HEAT AND MASS TRANSFER STUDY OF AN EVAPORATIVELY-COOLED RAILWAY COACH

by

S. N. MURTHY

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

MARCH, 1985

HEAT AND MASS TRANSFER STUDY OF AN EVAPORATIVELY-COOLED RAILWAY COACH

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

S. N. MURTHY

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
MARCH, 1985

DEDICATED

TO

MY LOVING PARENTS

CERTIFICATE

This is to certify that the thesis entitled "HEAT AND MASS TRANSFER STUDY OF AN EVAPORATIVELY-COOLED RAILWAY COACH" by S. N. MURTHY is a record of work carried out under my supervision and has not been submitted elsewhere for a degree.

March, 1985

MANOHAR PRASAD
ASSISTANT PROFESSOR
DEPT. OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
KANPUR

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Dr.Manohar Prasad for his invaluable guidance and constant encouragement throughout the course of this work.

I am grateful to Dr. K. K. Saxena for his invaluable advice.

I am grateful to Mr. P. N. Misra for his technical and physical help.

I gratefully acknowledge RDSO Lucknow for supplying various information concerned with this work.

I am thankful to R. Pandey for the efficient typing of this work. Finally, I wish to thank Mr. B. K. Jain for his splendid drawings.

MURTHY, S. N.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

a_g	absorption coefficient of glass
A_{aw}	area of the air-washer ,m^2
A_c	cross-sectional area of the coach, m^2
A_f	net flow area, m^2
c_{pa}	specific heat of air,kJ/kg - ^oC
c_{pm_1}	specific heat of moist air at humidifier inlet, kJ/kg - ^oC
c_{pm_2}	specific heat of moist air at humidifier exit, kJ/kg - ^oC
C	diffuse radiation factor
d	solar decination angle, degrees
F_s	shading coefficient for glass window
$(F_{sg})_{sj}$	angle factor between the surface and the ground
$(F_{ss})_{sj}$	angle factor between the surface and the sky
Gr	Grashof number
H_p	occupant heat release per unit time, kJ/h-person.
h	hour angle, degrees
h_{gw}	height of the glass window, m
$(h_i)_{sj}$	inside convective heat transfer coefficient, kJ/h-m^2- ^oC
$(h_{iav})_{sj}$	average inside convective heat transfer coefficient kJ/h-m^2- ^oC
h_o	outside convective heat transfer coefficient, kJ/h-m^2- ^oC

I_{DN}	intensity of solar radiation normal to sun's rays at the l·cation, kJ/h-m^2
$(I_D)_{sj}$	intensity of direct solar radiation, kJ/h-m^2
$(I_d)_{sj}$	intensity of diffuse solar radiation, kJ/h-m^2
$(I_r)_{sj}$	intensity of reflected solar radiation, kJ/h-m^2
$(I_T)_{sj}$	intensity of total impinging solar radiation on the surface, kJ/h-m^2
K	extinction coefficient, mm^{-1}
L_{aw}	length of the air washer, m
L_h	height of the coach, m
L_l	length of the coach, m
L_w	width of the coach, m
l	latitude angle, degrees
l_{sj}	characteristic length, m
$\dot{m}_a$	air flow rate, kg/h
M_p	moisture rele se per person per unit time, kgw/h-person
n_g	index of refraction for glass
n_p	no. of passengers in the coach
n_w	no. of windows on one side of the coach
Nu	Nusselt number
p	atmospheric pressure, bars
p_v	partial pressure of water vapour, bars
p_s	saturation pressure of water vapour, bars
Pr	Prandtl number

P_c	perimeter of the cross-section of the coach, m
q'''	occupant heat generation per unit volume of the coach, $(kJ/h\text{-}m^3)$
Q_c	heat input due to conduction through walls, floor and ceiling, (kJ/h)
Q_R	occupant heat release inside the coach, kJ/h
Q_{ST}	total heat input through structure due to conduction and solar radiation, kJ/h
Q_v	air flow rate through the washer, m^3/h
r	fraction of recirculation of coach exit air
r_{cs}	specular reflectivity of glass for single radiation component
Re	Reynolds number
R_j	resistance of structural component, $m^2\text{-}h\text{-}{}^oC/kJ$
t_g	thickness of window glass, mm
T	temperature of air inside the coach, ^oC
ΔT	temperature rise within the coach, ^oC
$(\Delta T_{wi})_{sj}$	temperature difference between inside wall temperature and air temperature inside the coach, ^oC
T_a	dry-bulb temperature of air at inlet to regenerative heat-exchanger, ^oC
T_{av}	average temperature inside the coach
T_{db}	dry-bulb temperature of ambient air, ^oC
T_m	mean temperature of air inside the coach, ^oC
T_2	temperature of air at inlet of the coach, ^oC
$(T_{sol})_{sj}$	sol-air temperature, ^oC
T_e	temperature of air at exit of the coach, ^oC

T_{wb}	wet-bulb temperature of ambient air, ^{o}C
T'_{wb}	wet-bulb temperature of air at inlet to regenerative heat-exchanger, ^{o}C
T_{wbd}	wet-bulb depression, ^{o}C
U_{sj}	overall heat transfer coefficient, $kJ/h\text{-}m^2\text{-}^{o}C$
v	specific volume of moist air, m^3/kg dry air
V	train velocity, km/h
V_{aw}	volume of the air-washer m^3
V_{fc}	forced convection velocity, m/s
V_{cv}	comfort velocity, m/s
w	specific humidity of air inside the coach, kgw/kg dry air
w'''	moisture release by persons per unit time per unit volume of the coach, $kgw/h\text{-}m^3$
w_a	specific humidity of ambient air, kgw/kg dry air
w'_a	specific humidity of air at exit of the regenerative heat exchanger, kgw/kg dry air
w_2	specific humidity of air at coach inlet , , kgw/kg dry air
w_e	specific humidity of air at coach exit, kgw/kg dry air
w'''	moisture release by persons per unit time per unit volume of the coach, $kgw/h\text{-}m^3$
x	dimensional co-ordinate for coach length, m
x_m	mean dimensional co-ordinate, m
Y_{sj}	ratio of sky diffuse radiation on vertical surface to that on horizontal surface .

GREEK SYMBOLS

α_{cs}	solar absorptivity of glass for single radiation component
α_{Ds}	solar absorptivity of glass for direct radiation
α_{ds}	solar absorptivity of glass for diffuse radiation
α_{rs}	solar absorptivity of glass for reflected radiation
α_{j}	solar absorptivity of the surface
	solar altitude angle degrees
η	humidifier efficiency
Φ	solar azimuth angle measured from south, degrees
Φ_a	relative humidity of ambient air
Φ_2	relative humidity of air at coach inlet
Φ_e	relative humidity of air at coach exit
γ_{sj}	surface solar azimuth angle measured from south, degrees.
Ψ_s	surface azimuth angle measured from south degrees
θ_{sj}	angle of incidence of solar radiation, degrees.
τ_{cs}	transmissivity of glass for single radiation component
τ_{Ds}	transmissivity of glass for direct radiation
τ_{ds}	transmissivity of glass for diffuse radiation
τ_{rs}	transmissivity of glass for reflected radiation
ρ_{cs}	reflectivity of glass for single radiation component

σ_s	amount of radiation transmitted through glass window $kJ/m^2 - h$
δ_{sj}	tilt angle of the surface measured from the horizontal.
ε	regenerative heat exchanger effectiveness.

ABSTRACT

The cooling load for a railway coach has been computed from the governing equations formulated on the basis of heat and mass transfer analyses. A generalized computer program has been formulated for the same for three main routes of Indian Railways for which evaporative cooling can be used. The results have been obtained for the coach moving with a given velocity for various places with the known latitudes, longitudes and outside summer design conditions.

The non-regenerative and regenerative evaporative cooling systems have been considered. They have been compared with each other in terms of tonnage and the comfort conditions within the coach. The latter is found to be a better choice from comfort point of view.

The higher inside condition without violating the comfort requirement is desirable as it can be achieved from the evaporative cooling with air flow rates ranging from 10,000 to 15,000 kg/h. For required comfort conditions, the computed results reveal that even 5-ton air conditioner will serve the purpose as compared to the existing 10-ton air conditioners used in railway coaches.

CHAPTER 1

1.1 INTRODUCTION

Evaporative cooling is the oldest known application of air-conditioning principles. In the prescientific era, it flourished as a natural process of cooling mainly in the hot-dry and lightly populated desert areas. Even in the scientific era, it did not get much attention as is evident from the fact that as late as 1958, the official American Society of Heating and Air-conditioning Engineers' Guide comprising 1272 pages, devoted only half a page and that too without tables or data. But, it started gaining due attention in the modern scientific era, only after the 1960's, when the cost of energy started escalating due to severe energy crisis. Hence the mechanically refrigerated conventional air-conditioners became very expensive beyond the means of average income-group people. Thus the former was looked to be a promising cheap alternative method of air-conditioning. This is supported by the fact that the ASHRAE Handbook [1] devotes a separate chapter on evaporative air cooling and related equipment. However, it did not receive much scientific impetus then as it was considered to be feasible only in particular areas and is impractical for other areas, like the coastal regions. Unfortunately, it was not realized that the sea itself acts as a natural evaporative cooling device as is evident from the temperature of the mainland compared to only about 35°C of the sea coast. Hence, in the coastal areas, the human

comfort conditions can be maintained by high rates of air circulation over the body.

Prehistoric evaporative cooling started around 3000 B.C., when in India, evaporation was even used to make ice [2]. In rural India, the people still use the ancient cocos tatti of great effectiveness. In olden days doors were replaced in summer by tatties, frameworks similar to screen doors covered with dried khuss -khuss grass which were kept wet by coolies. The most popular is the Indian evaporative air cooler,known for over 50 years ,where instead of door, a wheel like framework covered with khuss-khuss grass is revolved and kept moist by coolies. Like tatties, the grass lends a pleasant odour . Another classic example is the use of earthen pots for cooled drinking water.

These days evaporative cooling is gaining much importance. Several workers have tried to get optimum performances of desert coolers [3,4,5] based on pad density, water spray over the pads etc. The evaporative cooling has also been used in cars and in buses [6] because of cheaper system. A proposal is under way for use of evaporative cooling in Indian Railways [7].

1.2 THEORY OF EVAPORATIVE COOLING:

There are two types of evaporative cooling :direct and indirect. The principle underlying the former is conversion of sensible heat of air into latent heat of vaporization of water added directly into the air. In the

latter, the air is cooled by the evaporation of water not contacting it, so that the sensible cooling of air occurs without increase in its moisture content [8].

The exchange of sensible heat for latent heat under the isolated conditions results in the lowered temperature of air and the air becomes eventually saturated at the water temperature. This process is called 'adiabatic saturation' since there is no external heat exchange between the system and surroundings. The practical applications of this principle is found in pump-equipped drip -type coolers, slinger and rotary pad-coolers, most commercial air washers having spray-chamber or capillary design and some textile-mill cooling systems.

In practice however, the water usually gains some external sensible heat in the sump tank, pump and piping. The make-up water entering the sump to replace the evaporated and lost water adds heat. Other sources of heat addition include circulatory friction, heat transfer from the surroundings and possible solar radiation. Thus most adiabatic saturation' in evaporative cooling is merely a close approximation, with considerable evaporation occurring to cool or recool water. When the circulating water is considerably warmer than the air wet-bulb temperature during initial contact, the process resembles that occurring in most cooling towers for cooling warm condenser water. Air and water are jointly cooled and not the air alone. This occurs in direct evaporative cooling systems having 'once-through' or pumpless use of water,

as in many small drip-type coolers, some spray-chamber and capillary air-washers. More water is consumed and the cooled air is both warmer and more humid than in true adiabatic saturation.

There are limits to the cooling achieved by adiabatic saturation. The amount of sensible heat removed equals the latent heat required to saturate the air with water vapour. The cooling possibilities of adiabatic saturation vary inversely with the existing degree of humidity of air.

Most commercial direct evaporative coolers deliver air cooled about 70 to 95% towards saturation. This is only 50-70 percent for inexpensive drip-type coolers, but for slinger and air-washer types, this amounts to over 90 percent of perfect humidification. A ratio known as saturating or saturation efficiency (η) is used for rating the performance of such devices. It is given by:

$$\eta = \frac{T_{db} - T}{T_{db} - T_{wb}} \qquad (1.1)$$

where T_{db} = entering air dry-bulb temperature (^oC).

T_{wb} = entering air wet bulb temperature (^oC).

and T = the dry-bulb temperature of air leaving the system (^oC).

However, the performance of evaporative coolers will be badly affected if heat enters the process from any source other than the air being cooled. In view of this it is recommended that evaporative coolers be (i) located

in the shade wherever possible, (ii) have the coolest possible water supply and (iii) receive the coolest and driest air.

1.3 USE OF EVAPORATIVE COOLING IN RAILWAY COACHES

The Indian Railways also desires to use evaporative cooling, especially in the three-tier sleeper coaches because the passengers feel very uncomfortable during summer season. There is considerable scope of evaporative cooling for trains plying in the areas away from the coastal regions.

We met the authorities at RDSO Lucknow in July 1984. They supplied us various drawings and relevant data. We also surveyed the existing air-conditioning systems of the railway coaches. As such, they do not possess any standard method or data for cooling load calculations [9]. They use 10-ton conventional air-conditioning unit divided into two separate units of 5 ton each. The cooling of air is done from both ends. The air is distributed uniformly through a central duct on both sides.

So we carried out the preliminary analyses and the results published recently [10]. Further, calculations were carried out on the use of evaporative cooling for railway coaches. The comfort conditions were estimated using Fanger's comfort equation for temperatures below 28 °C. It is found that the same lies in the comfort zone. Use of evaporative cooling with regeneration reveals that it can give the desired comfort conditions at the cost of additional equipment.

1.4 PRESENT CONTRIBUTION

A computer program has been developed to calculate the cooling load, temperature distribution inside the coach and other parameters of interest at any place for a given time and velocity of moving coach with known outside summer design conditions. Also, the effect of the mode of inside convective heat transfer on the overall heat transfer rate has been studied. The heat and mass transfer analyses have been carried out for two separate cooling systems for evaporative cooling in the railway coach and their usefulness compared in terms of energy saving and achieved comfort conditions inside the coach. The effect of various coach parameters on the tonnage and temperature distribution inside the coach has been thoroughly investigated.

It has been found that the regenerative system yields better comfort conditions but involves more number of components. The computed cooling load is found to be barely half of the capacity of existing air conditioners for the railway coaches.

It has also been found that the water requirement for evaporative cooling for 6-hour service duration is found to quite reasonable for being carried by the train.

CHAPTER 2

MATHEMATICAL FORMULATION

2.1 DESCRIPTION OF THE SYSTEM

The air-conditioning of the railway coach is done using mechanical refrigeration system. The compressor and condenser are mounted underneath the coach. The air-cooled condenser having a blower is used to cool compressed vapour. The condensate is supplied to the cooling coil mounted at the ends of the air-conditioned coach. The air is distributed through a constant area duct to both sides of the coach.

In the present analysis, the evaporative cooling is envisaged to get temperature in the range of 28 to 34 °C. The air is supplied from one end and is exhausted to the other end. The evaporative cooling units are mounted in the space of the vapour-compression machine. Even water-tank is accommodated in the same space. This is done in order to avoid further complexity.

2.2 MATHEMATICAL TREATMENT

Figure 2.1 shows a 3 Tier broad gauge CSC 1640 II class sleeper coach with dimensions. A differential segment dx has been marked showing heat and mass transfer. Then, for the control volume we write the mass and energy conservation equation as:

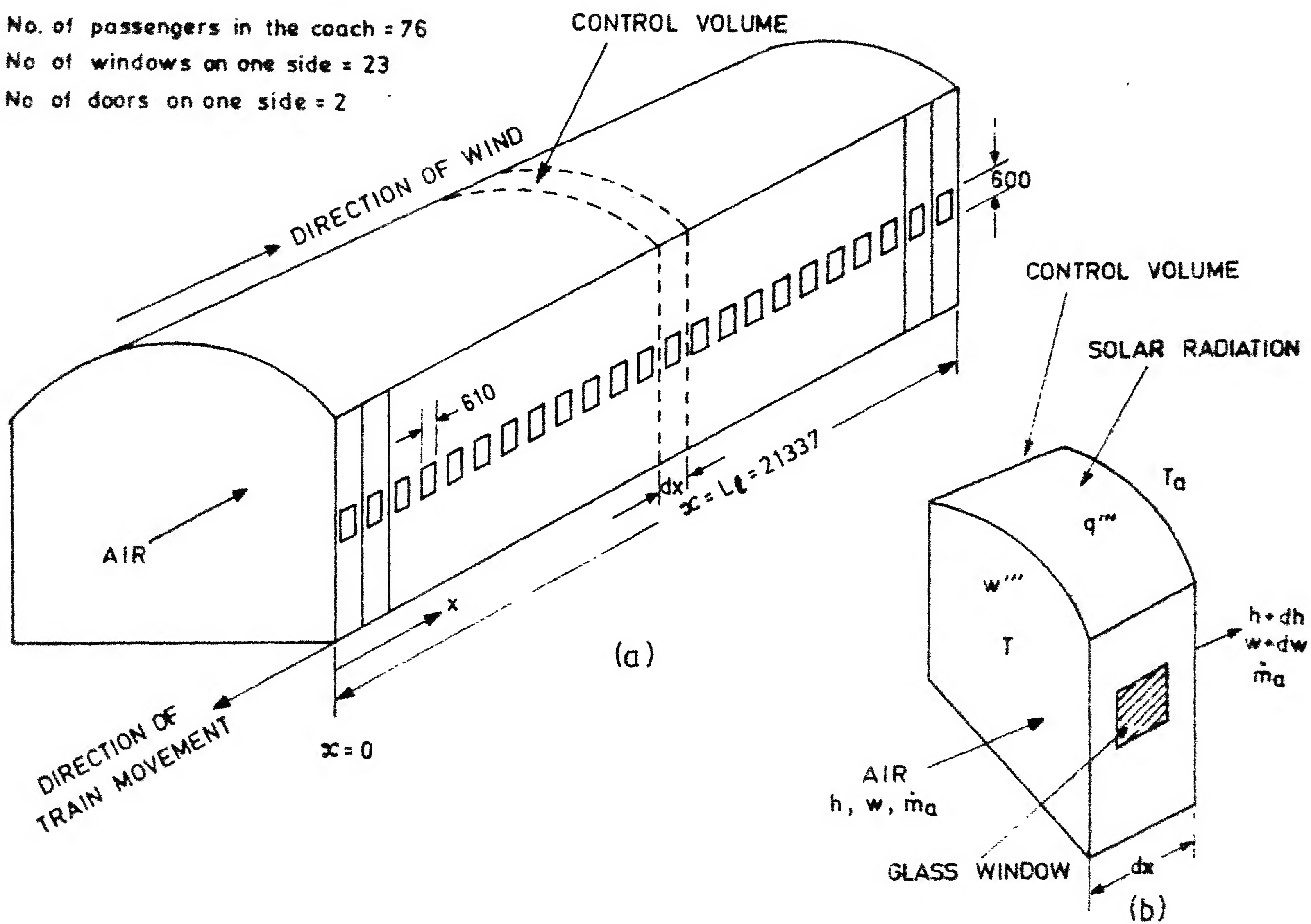

Fig. 2.1 Schematic representation of railway coach.

GOVERNING EQUATIONS

2.2.1 Mass transfer:

The conservation of moisture component, is:

$$\dot{m}_a \; dw = w''' . A_c . \; dx \tag{2.1}$$

where A_c = cross-sectional area of the coach (m^2).

$\dot{m}_a$ = mass flow rate of air (kg/h).

w''' = moisture release by persons per unit time per unit volume of the coach ($kgw/h\text{-}m^3$).

$$w''' = M_p \, n_p/(A_c \times L_1) \tag{2.2}$$

where M_p = moisture release per person per unit time (kgw/h-person).

n_p = no. of passengers in the coach.

L_1 = length of the coach (m).

On integration of Eq. (2.1) with boundary condition ($x = 0$, $w = w_2$) one gets :

$$w = (w''' A_c/\dot{m}_a) \, x + w_2 \tag{2.3}$$

where w_2 = specific humidity of air at inlet to the coach (kgw/kg dry air).

w = specific humidity of air (kgw/kg dry air).

2.2.2 Heat transfer:

The heat transfer equation for the control volume is written as:

$$\dot{m}_a \; dh = đQ_R + đQ_s + đQ_c = đQ_R + đQ_{ST} \tag{2.4}$$

where $\dot{d}Q_R$ = occupant heat release inside the control volume (kJ/h).

$\dot{d}Q_S$ = heat input to control volume dx due to solar radiation (kJ/h).

$\dot{d}Q_C$ = heat input to control volume dx due to conduction through walls, floor and ceiling (kJ/h).

$\dot{d}Q_{ST}$ = total heat input through structure due to conduction and solar radiation to control volume (kJ/h).

The specific enthalpy of moist air is expressed as:

$$h = c_{pa}\, T + w\,(2501.4 + 1.884\, T) \qquad (2.5)$$

where T = temperature of air inside the coach (^{o}C).

Using Eqs. (2.3) and (2.5), we have

$$h = c_{pa}\, T + [\,(w''' \; A_c/\dot{m}_a\,)\, x + w_2\,](2501.4 + 1.884\, T) \qquad (2.6)$$

and using c_{pa} = 1.004 we have

$$\frac{dh}{dx} = (1.004 + 1.884\, w_2) \frac{dT}{dx} + (1.884\, w''' A_c/\dot{m}_a)\, x.\, \frac{dT}{dx} + (1.884\, w''' A_c/\dot{m}_a\,)T + 2501.4\, w''' A_c/\dot{m}_a \qquad (2.7)$$

The heat generation is written as:

$$\dot{d}Q_R = q''' A_c\, dx \qquad (2.8)$$

where q''' is the occupant heat generation per unit volume of the coach (kJ/h-m^3).

$$q''' = H_p\, n_p/(A_c \times L_1) \qquad (2.9)$$

where H_p = occupant heat release per unit time (kJ/h-person).

The structure load dQ_{ST} can be determined after making the following preliminary calculations:

(i) A_j (Area of surface, m^2):

$$A_j = f_j . dx \tag{2.10}$$

For side wall (j = 1);

$$A_1 \left[(L_1 L_h - n_w A_w)/L_1 \right] dx = f_1 . dx \tag{2.11}$$

where, L_h = height of the coach (m).

n_w = no. of windows on one side of the coach.

A_w = Area of one window (m^2).

For ceiling (j = 2):

$$A_2 = \left[(P_c - 2L_h - L_w)/2 \right] dx = f_2 . dx \tag{2.12}$$

where P_c = perimeter of the cross-section of the coach (m).

L_w = width of the coach (m) (Fig. 2.2).

For glass window (j = 3):

$$A_3 = \left[(n_w A_w)/L_1 \right] . dx = f_3 . dx \tag{2.13}$$

For floor (j = 4):

$$A_4 = (L_w/2) . dx = f_4 . dx \tag{2.14}$$

(ii) $(I_T)_{sj}$ (Intensity of total impinging solar radiation on the surface, kJ/h-m^2):

(a) h (Hour angle, degrees):

Local Apparent Time (L.A.T.) of the given place [11] is related to the local Mean Time (L.M.T.) as :

L. A. T. = L. M. T. + Equation of time with L. M. T. given by L. M. T. = I. S. T. + correction where I. S. T. = Indian Standard Time

and correction = $4\,[(L_o)_p - (L_o)_{sm}]$(minutes)

with $(L_o)_p$ = Longitude of the place in degrees.

$(L_o)_{sm}$ = Longitude of standard meridian in degrees

For May 21, equation of time = $+3^m\ 37^s$

$$\therefore \quad \text{L. A. T.} = \text{L. M. T.} + 3^m\ 37^s \tag{2.15}$$

The hour angle (h) with L. A. T. in hours is given by:

$$h = 15\ (\text{L. A T} - 12.00) \tag{2.16}$$

(b) I_{DN} (Intensity of solar radiation normal to sun's rays at the location, kJ/h-m^2):

The solar altitude angle (β)[12]latitude of the place (l), declination angle (d) and the hour angle (h) all in degrees are related as [12]:

$$\sin \quad = \cos(l)\ \cos(d)\ \cos(h) + \sin(l)\ \sin(d) \tag{2.17}$$

We have

$$I_{DN} = A/\exp\ (B/\sin\beta) \tag{2.18}$$

where A and B are constants depending on the time of the year [13].

(c) $(I_D)_{sj}$ (Intensity of direct solar radiation, kJ/h-m^2): from Fig. 2.2, one gets:

$$\cos\Phi = (\sin\beta\ \sin l - \sin d)/(\cos\beta\ \cos l) \tag{2.19}$$

where Φ = solar azimuth angle measured from south

For solar noon (h = 0), Φ = 0.

P_C = Perimeter of cross section of the coach (m)

A_C = Area of cross-section (m^2)

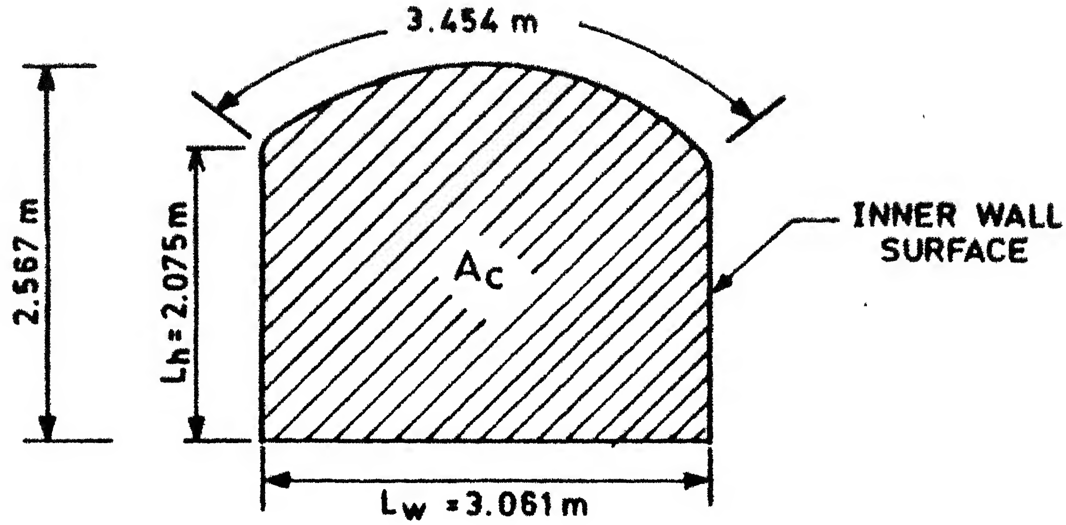

Fig. 2.2. Cross-sectional view of the inside wall of railway coach.

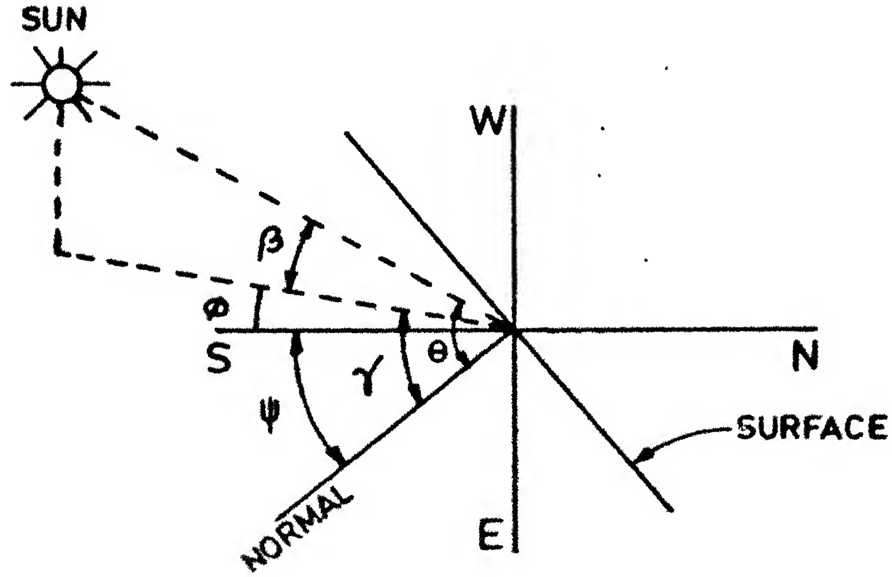

Fig. 2.3 Various solar angles.

For sidewalls and window ($j = 1$ and $j = 3$):

$$\cos(\theta_{sj}) = \cos\beta \cos\gamma_{sj} \quad (2.20)$$

where θ_{sj} = angle of incidence of solar radiation.

γ_{sj} = surface solar azimuth angle measured from south.

If Ψ_s = surface azimuth angle measured from south, γ_{sj} can be obtained from the known values of Φ and Ψ_s for various train routes(Table 2.1):

TABLE 2.1

VALUES OF Ψ AND γ FOR DIFFERENT TRAIN ROUTES (Fig. 2.4) [12]

Train Route	Orientation of Coach	East facing side of coach			West facing side of coach		
		Ψ_1	γ_{1j}(a.m)	γ_{1j}(p.m.)	Ψ_2	γ_{2j}(a.m.)	γ_{2j}(p.m.)
South-East	NW-SE	135°	$\Phi-\Psi_s$	$\Phi+\Psi_s$	45°	$\Phi+\Psi_s$	$\Phi-\Psi_s$
South	N-S	90°	$\Phi-\Psi_s$	$\Phi+\Psi_s$	90°	$\Phi+\Psi_s$	$\Phi-\Psi_s$
South-West	NE-SW	45°	$\Phi-\Psi_s$	$\Phi+\Psi_s$	135°	$\Phi+\Psi_s$	$\Phi-\Psi_s$

If $\gamma_{sj} > 90^\circ$ i.e. $\cos\theta_{sj} < 0$, the surface is in the shade and the intensity of direct solar radiation impinging on the surface $(I_D)_{sj} = 0$.

For celing ($j = 2$):

$$\cos(\theta_{sj}) = \sin\beta \quad (2.21)$$

Here the ceiling has been assumed to be approximately horizontal in spite of its curvature:

Thus,

$$(I_D)_{sj} = I_{DN} \cos(\theta_{sj}) \quad (2.22)$$

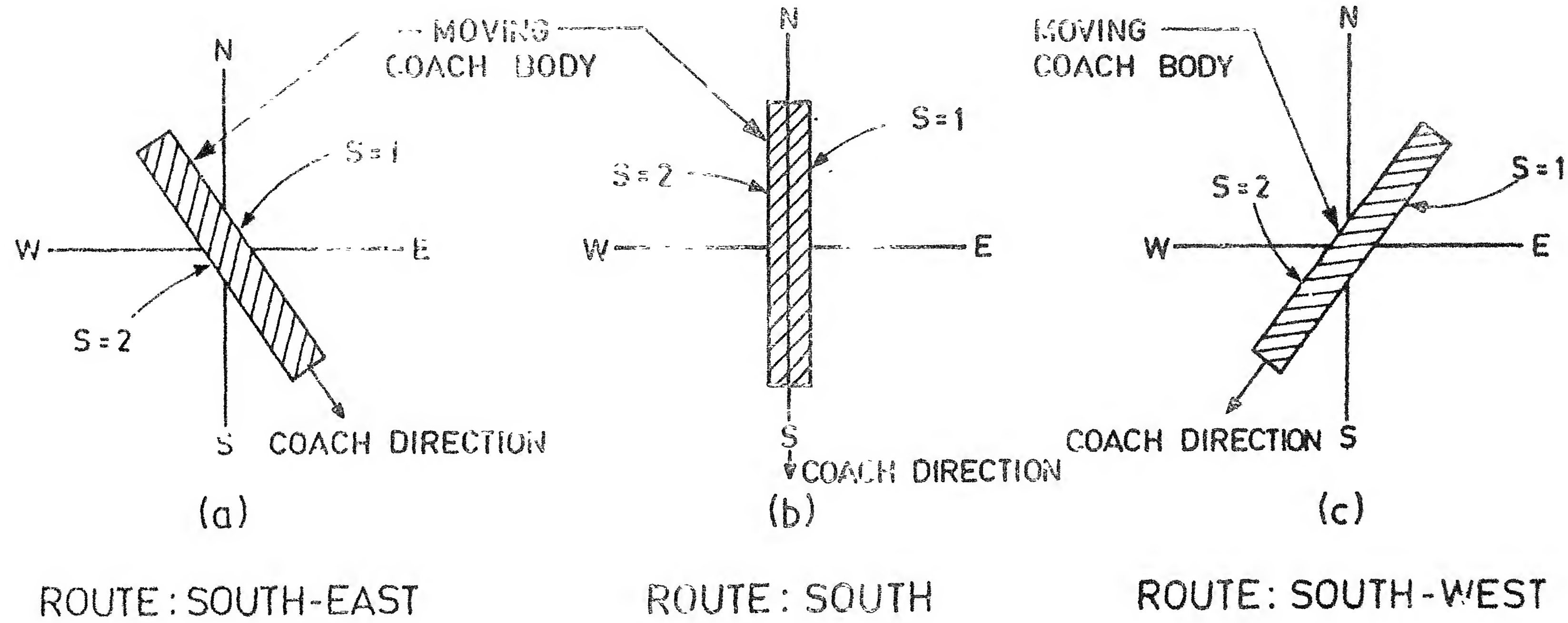

Fig. 2.4. Schematic representation of the various routes of the railway coach.

(d) $(Id)_{sj}$ Intensity of diffuse radiation (kJ/h-m^2)

For sidewalls or glass window ($j = 1$ or $j = 3$):

$$(I_d)_{sj} = C\, I_{DN}\, Y_{sj}$$

where C = diffuse radiation factor.

$$Y_{sj} = \frac{\text{sky diffuse on vertical surface}}{\text{sky diffuse on horizontal surface}}$$

where Y_{sj} is given by

$$Y_{sj} = 0.55 + 0.437 \cos(\theta_{sj}) + 0.313 \cos^2(\theta_{sj}) \text{ for } \cos\theta_{sj} > -0.2 \qquad (2.23)$$

For $\cos\theta_{sj} \leq -0.2$ $\quad Y_{sj} = 0.45$ [14].

For ceiling ($j = 2$):

$$(I_d)_{sj} = C\, I_{DN}\, (F_{ss})_{sj} \qquad (2.24)$$

where $(F_{ss})_{sj}$= angle factor between the surface and the sky.

If $(\delta)_{sj}$ = tilt angle of the surface measured from the horizontal, then;

$$(F_{ss})_{sj} = (1 + \cos\delta_{sj})/2 \quad = 1.0 \quad \because \delta_{sj} = 0\;)$$

(e) $(I_r)_{sj}$ (Intensity of reflected radiation, kJ/h-m^2):

$$(I_r)_{sj} = I_{tH}\, \rho_{gr}\, (F_{sg})_{sj} \qquad (2.25)$$

where I_{tH} = total radiation (including sky diffuse and direct) falling on the ground (kJ/h-m^2).

ρ_{gr} = reflectivity of ground.

$(F_{sg})_{sj}$= angle factor between the surface and the ground.

We have

$$I_{tH} = I_{DN}\,(C + \sin\beta) \qquad (2.26)$$

and $(F_{sg})_{sj} = [\ 1 - \cos \delta_{sj}\ ]/2$ (2.27)

For sidewalls and window (j = 1 and j = 3):

$$\delta_{sj} = 90^\circ, \quad \therefore \quad (F_{sg})_{sj} = 0.5$$

For ceiling (j = 2):

$$\delta_{sj} = 0, \quad \therefore \quad (F_{sg})_{sj} = 0.$$

Hence no. reflected radiation falls on the ceiling.

From the above the total radiation $(I_T)_{sj}$ impinging on a surface is found as:

For sidewalls and celing:

$$(I_T)_{sj} = (\ I_D + I_d + I_r)_{sj} \qquad (2.28)$$

For floor:

$(I_T)_{sj} = 0$ since negligible solar radiation is assumed to impinge on the bottom of the coach.

(iii) h_o (outside convective heat transfer coefficient, $kJ/m^2 - h - {}^oC$):

Assuming a transitional Reynolds number of 3×10^5 and a train velocity V (km/h) greater than or equal to 60 km/h we have

$$x_{cr} \ll L_1 \qquad (2.29)$$

so the whole flow can be assumed to be turbulent. Hence

$$Nu_x = 0.0292\ (Re_x)^{0.8}\ \ (Pr)^{1/3} \qquad (2.30)$$

for forced convection turbulent flow over a flat plate [15]

Using Eq. (2.30) and taking the properties of air at the mean coach outside temperature lof 38 °C , we get:

$$h_o = 0.0243\ (V \times 1000)^{0.8}\ (x_m)^{-0.2} \qquad (2.31)$$

x_m = mean distance (m) of the control volume from $x = 0$.

The above eq. (2.31) holds good when the supply of air is in the same direction as the velocity of the train. If they are in the opposite directions, we have

$$h_o = 0.0243\ (V \times 1000)^{0.8}\ (L_1 - x_m)^{-0.2} \qquad (2.32)$$

(iv) R_j (Resistance of structural component, $m^2 - h - {}^oC/kJ$)

The values of resistances of various structural components of the coach viz. sidewall, glass window , ceiling and floor have been calculated according to their individual structural details given by the drawing [16] and have been found from the air gap resistances [17] as:-

Sidewall : $R_1 = 0.0560\ m^2 - h - {}^oC/kJ$.

Ceiling : $R_2 = 0.0704\ m^2 - h - {}^oC/kJ$.

Glass Window : $R_3 = 0.00127\ m^2 - h - {}^oC/kJ$ which is quite negligible.

Floor : $R_4 = 0.1139\ m^2 - h - {}^oC/kJ$.

(v) $(h_i)_{sj}$ (Inside convective heat transfer coefficient, $kJ/h-m^2$):

Two cases have been considered to study the effect of internal mode of convective heat transfer on the net cooling load . They are: (a) CASE I: Forced convection for ceiling and free convection on other sides of the coach and (b) CASE II : Forced convection on all sides of the coach.

(a) CASE I: Forced convection for ceiling and free convection on other sides of the coach.

For ceiling ($j = 2$):

Assuming a transitional Reynolds number of 3×10^5 x_{cr} is calculated from the forced convection velocity of air flow (V_{fc}) under the ceiling . If A_f is the net flow area (m^2) then

$$V_{fc} = \dot{m}_a \, v/(A_f \times 3600) \qquad (m/s) \qquad (2.33)$$

where v = specific volume of moist air (m^3/kg of dry air) whose value is taken to be 0.87 m^3/kg dry air.

The values of V_{fc} estimated from Eq. (2.33) for different air flow rates range from 0.5 - 2.0 m/s and the corresponding x_{cr} values have been found to be greater than half the length of the coach (L_1). Hence the flow beneath the ceiling is partly turbulent and partly laminar and an average film coefficient $(h_{iav})_{sj}$ a can be found from the following [18]:

$$Nu_L = 0.036 \, (Pr)^{1/3} \, [(Re_L)^{0.8} - 18700] \qquad (2.34)$$

from which we have

$$(h_{iav})_{sj} = [\, 0.0302 \, (V_{fc} \times 3600)^{0.8} (L_1)^{0.8} - 57.6]/L_1$$
$$(kJ/h\text{-}m^2\text{-}^{\circ}C) \qquad (2.35)$$

Other sides ($j \neq 2$):

Since free convection has been assumed, Grashof number is calculated for all the other sides.

For air:

$$(Gr.Pr)_{sj} = 1.6 \times 10^{-6} \, l_{sj}^{\,3} \; (\Delta T_{sj}) \qquad (2.36)$$

where l_{sj} = characteristic length (m) .

ΔT_{sj} = temperature difference between that of the surface and the flowing air (^{o}C).

For sidewall ($j = 1$):

$$l_{sj} = L_h \text{ and } 10^8 < (Gr.Pr)_{sj} < 10^{12} \quad (2.37)$$

From Eq. (2.37) it can be deduced that free convection flow over the sidewall is turbulent. Hence,

$$(h\ )_{sj} = 4.74\ )\ (\Delta T_{wi})_{sj}^{0.33} \text{ (for vertical plates)} \quad (2.38)$$

where

$(h_i)_{sj}$ = inside heat transfer coefficient (kJ/h-m^2- ^{o}C)

$(\Delta T_{wi})_{sj}$ = temp. difference between inside wall surface and inside mean air temperature (^{o}C)

$(\Delta T_{wi})_{sj}$ can be given by:

$$(\Delta T_{wi})_{sj} = (T_{wi})_{sj} - T_m \quad (2.39)$$

where

$(T_{wi})_{sj}$ = inside surface temperature of the coach (^{o}C).

T_m = mean inside air temperature of the coach (^{o}C).

Since the coach has been divided into 23 elements of equal length, i varied from 1 to 23. Hence

$$(T_m)_i = (T_i + T_{i+1})/2 \quad (^{o}C) \quad (2.40)$$

where T_i = Temperature of inside air at the i^{th} section (^{o}C).

T_{i+1} = temperature of inside air at the $(i + 1)^{th}$ section (^{o}C). For $i = 1,2,.........23$

For glass window ($j = 3$):

$$l_{sj} = h_{gw} \text{ and } 10^4 < (Gr.Pr)_{sj} < 10^{12} \quad (2.41)$$

where h_{gw} = height of the glass window (m).

Hence free convection is laminar and

$$(h_i)_{sj} = 5.11 \, [\, (\Delta T_{wi})_{sj}/l_{sj} \,]^{0.25} \quad (kJ/h\text{-}m^2\text{-}^{o}C) \tag{2.42}$$

(for vertical plates):

For a known h_{gw} = 0.600 m Eq. (2.42) turns out to be

$$(h_i)_{sj} = 5.80 \, (\Delta T_{wi})_{sj}^{0.33} \tag{2.43}$$

For floor (j = 4):

$$l_{sj} = L_1 \text{ and } 10^8 < (Gr.Pr)_{sj} < 10^{12} \tag{2.44}$$

Hence free convection is turbulent. However the floor is equivalent to a heated plate facing upward. So the appropriate equation for this is

$$(h_i)_{sj} = 5.47 \, (\Delta T_{wi})_{sj}^{0.33} \tag{2.45}$$

For $j \neq 2$, $(\Delta T_{wi})_{sj}$ is determined using 'Newton-Raphson method'. We have:

$$U_{sj} \, [(T_{sol})_{sj} - T \,] = (h_i)_{sj}[(T_{wi})_{sj} - T_m] = (h_i)_{sj}(\Delta T_{wi})_{sj} \tag{2.46}$$

where U_{sj} = overall heat transfer coefficient (kJ/h-m^2- ^{o}C).

$(T_{sol})_{sj}$ = sol-air temperature (^{o}C) the evaluation of which is explained in (vi).

T = temperature of air inside the coach (^{o}C).

Also, $$U_{sj} = 1/[(1/h_o) + R_j + 1/(h_i)_{sj}] \tag{2.47}$$

Using Eq. (2.46), we have:

$$(T_{sol})_{sj} - T = (h_i)_{sj} \, (\Delta T_{wi})_{sj}/U_{sj} \tag{2.48}$$

Putting $(h_i)_{sj} = C_j(\Delta T_{wi})_{sj}^{m_j}$ and using Eq. (2.47), we have:

$$(T_{sol})_{sj} - T = (h_i)_{sj}(1/h_o + R_j + 1/(h_i)_{sj})(\Delta T_{wi})_{sj}$$

$$= (\Delta T_{wi})_{sj} + (h_i \Delta T_{wi})_{sj} (R_j + 1/h_o$$

$$(T_{sol})_{sj} - T = (\Delta T_{wi})_{sj} + C_j (\Delta T_{wi})_{sj}^{m_j+1} (R_j + 1/h_o)$$

Putting $(T_{sol})_{sj} - T = u'$ and $C_j(R_j + 1/h_o)\ u''$, we have (2.49)

$$(\Delta T_{wi})_{sj} + u'' (\Delta T_{wi})_{sj}^{m_j+1} - u' = 0 \qquad (2.50)$$

Eq. (2.43) is of the form:

$$f\ (\Delta T_{wi})_{sj} = 0 \qquad (2.51)$$

and using Newton-Raphson iteratioe technique to determine $(\ T_{wi})_{sj}$, we have:

$$[(\Delta T_{wi})_{sj}]_{n+1} = [(\Delta T_{wi})_{sj}]_n - f[(\Delta T_{wi})_{sj}]_n / [f'(\Delta T_{wi})_{sj}]_n \qquad (2.52)$$

where $[f'(\Delta T_{wi})_{sj}] = \dfrac{df}{d(\Delta T_{wi})_{sj}}$ and is given by

$$f'(\Delta T_{wi})_{sj} = 1 + (m_j+1)\ u'' (\Delta T_{wi})_{sj}^{mj} \qquad (2.53$$

The above iteration is of second order.

(b) CASE II: Forced convection on all sides of the coach:

For ceiling:

The same eq. (2.35) used for case I is applicable. Hence

$$(h_{iav})_{sj} = [\ 0.0302\ (V_{fc} \times 3600)^{0.8}\ (L_1)^{0.8} - 57.6]/L_1 \qquad (2.54)$$

For sidewall and glass window:

$x_{cr} > L_h$ for a transitional Reynolds number of 3,00,000 which means that the flow is laminar throughout the

surface.

$$\therefore \quad Nu_L = 0.664\ (Re_L)^{1/2}\ (Pr)^{1/3} \tag{2.55}$$

or, $(h_{iav})_{sj} = 0.237\ (V_{fc})^{0.5}\ (L_h)^{-0.5}$

For floor: The flow is partly laminar and partly turbulent as in the case of ceiling and again we have

$$(h_{iav})_{sj}\ [\ 0.0302\ (V_{fc} \times 3600)^{0.8}\ (L_1)^{0.8} - 57.6]/L_1 \tag{2.56}$$

(vi) $(T_{sol})_{sj}$:-

For ceiling and sidewall :

$$(T_{sol})_{sj} = T_{db} + \alpha_j\ (I_T)_{sj}/\ h_o \tag{2.57}$$

where,

α_j = solar absorptivity of the surface.

For Floor: $\because\ (I_T)_{sj} = 0;\quad (T_{sol})_{sj} = T_{db}$ (2.58)

For glass window:

$$(T_{sol})_{sj} = T_{db}\ [F_s\ \alpha_{Ds}\ (I_D)_{sj} + \alpha_{ds}\ (I_d)_{sj} + \alpha_{rs}\ (I_r)_{sj}]/h_o \tag{2.59}$$

where α_{Ds} = solar absorptivity of glass for direct radiation.

α_{ds} = solar absorptivity of glass for diffuse radiation

α_{rs} = solar absorptivity of glass for reflected radiation.

F_s = shading coefficient assumed to be 1.0 due to negligible shading over window glass.

α_{Ds}, α_{ds} and α_{rs} can be determined from the following:

Assuming common window glass ~~of~~ thickness t_g of double-strength quality, we have:

$$a_g = e^{-K\, t_g} \qquad (2.60)$$

where a_g = absorption coefficient of glass.

K = extinction coefficient [19].

$$t_g' = t_g/(\sqrt{1 - \sin^2(\theta_{cs})/n_g^2}\,) \qquad (2.61)$$

where n_g = index of refraction for glass.

θ_{cs} = incident angle for radiation component (°).

Direct radiation component: $\theta_{cs} = \theta_{sj}$ (2.62)

D (c = 1)

Diffuse radiation component : $\theta_{cs} = 60°$. A mean angle of (c = 2)

incidence of diffuse radiation has been assumed [20]

Reflected radiation component: $\theta_{cs} = 50°$ assumed [21].

Now $$\tau_{cs} = \frac{(1 - r_{cs})^2 a_g}{1 - r_{cs}^{\,2}\, a_g^2} \qquad (2.63)$$

where,

τ_{cs} = transmissivity of glass for single radiation component.

r_{cs} = specular reflectivity for single radiation component.

and $$\alpha_{cs} = 1 - r_{cs} - (1 - r_{cs})^2\, a_g / (1 - r_{cs}\, a_g) \qquad (2.64)$$

where α_{cs} = absorptivity of glass for single radiation component.

Using ρ_{cs} as reflectivity of glass for single radiation component, one gets $\rho_{cs} = 1 - \alpha_{cs} - \tau_{cs}$ as

$$\rho_{cs} + \alpha_{cs} + \tau_{cs} = 1.$$

Direct radiation component: $\tau_{Ds} = \tau_{1s}$, $\alpha_{Ds} = \alpha_{1s}$

Diffuse radiation component: $\tau_{ds} = \tau_{2s}$, $\alpha_{ds} = \alpha_{2s}$

Reflected radiation component: $\tau_{rs} = \tau_{3s}$, $\alpha_{rs} = \alpha_{3s}$

To calculate the amount of radiation (σ_s(kJ/m^2-h)) transmitted through glass window we use:

$$\sigma_s = (F_s \tau_{Ds} I_{Ds} + \tau_{ds} I_{ds} + \tau_{rs} I_{rs}) \ (\text{kJ/h-m}^2) \quad (2.65)$$

F_s = shading coefficient assumed to be 1.0 due to negligible shading of window glass.

Finally, we have:

$$dQ = \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} [(T_{sol})_{sj} - T] A_j + \sum_{j=3}^{3} \sum_{s=1}^{2} \sigma_s . A_j \quad (2.66)$$

Using Eqs. (2.4), (2.8), (2.9),(2.66) , we have:

$$\dot{m}_a \, dh = q''' A_c . dx + \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} . f_j [(T_{sol})_{sj} - T] . dx + \sum_{j=3}^{3} \sum_{s=1}^{2} \sigma_s . f_j . dx \quad (2.67)$$

From Eq. (2.67) we have:

$$\dot{m}_a \frac{dh}{dx} = q''' A_c + \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} f_j [(T_{sol})_{sj} - T] + \sum_{j=3}^{3} \sum_{s=1}^{2} \sigma_s . f_j . dx \qquad (2.68)$$

Also using eq. (2.7), one gets:

$$\dot{m}_a \frac{dh}{dx} = \dot{m}_a (1.004 + 1.884 w_i) \frac{dT}{dx} + (1.884 w''' A_c) x. \frac{dT}{dx} + (1.884 w''' A_c) T + 2501.4 w''' A_c \qquad (2.69)$$

Equations (2.68) and (2.69) yield:

$$\dot{m}_a (1.004 + 1.884 w_i) \frac{dT}{dx} + (1.884 w''' A_c) x \frac{dT}{dx} + (1.884 w''' A_c) T + 2501.4 w''' A_c = q''' A_c + \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} f_j (T_{sol})_{sj} + \sum_{j=3}^{3} \sum_{s=1}^{2} \sigma_s . f_j . dx - \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} . f_j \; T \qquad (2.70)$$

Now putting,

$$a = 1.004 + 1.884 w_i, \quad e = w''' A_c, \quad b = 1.884 w''' A_c,$$

$$\sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} f_j = m, \quad \sum_{j=1}^{4} \sum_{s=1}^{2} U_{sj} f_j (T_{sol})_{sj} + \sum_{j=3}^{3} \sum_{s=1}^{2} \sigma_s . f_j . dx = s,$$

Eq. (2.70) reduces to the form;

$$a\,\dot{m}_a \frac{dT}{dx} + bx\frac{dT}{dx} + bT + 2501.4\, e = q - m\,T + s \qquad (2.71)$$

$$\therefore (a\dot{m}_a + bx)\frac{dT}{dx} + (b + m)\, T = q + s - 2501.4\, e \qquad (2.72)$$

Further putting, $F_1 = (b + m)$ and $F_2 = (q + s - 2501.4\, e)$

We have,

$$(a\dot{m}_a + bx)\frac{dT}{dx} + F_1\, T = F_2 \qquad (2.73)$$

$$\text{i.e., } (a\,\dot{m}_a + bx)\frac{dT}{dx} = F_2 - F_1\, T \qquad (2.74)$$

$$\text{i.e., } \int \frac{dx}{a\,\dot{m}_a + bx} = \int \frac{dT}{F_2 - F_1\, T} \qquad (2.75)$$

$$\text{i.e. } \frac{1}{b}\log_e(a\,\dot{m}_a + bx) = -\frac{1}{F_1}\log_e(F_2 - F_1\, T) + C' \qquad (2.76)$$

where C = constant of integration

Using boundary conditions $x = 0,\ T = T_2$, where T_2 = temperature at inlet to the coach (^oC), we have

$$C' = \frac{1}{b}\log_e(a\,\dot{m}_a) + \frac{1}{F_1}\log_e(F_2 - F_1\, T_2) \qquad (2.77)$$

Using Eqs. (2.76) and (2.77), we have:

$$\frac{1}{b}\log_e(a\,\dot{m}_a + bx) = -\frac{1}{F_1}\log_e(F_2 - F_1\, T) + \frac{1}{a}\log_e(a\,\dot{m}_a)$$

$$+ \frac{1}{F_1}\log_e(F_2 - F_1\, T_2) \qquad (2.78)$$

$$\text{i.e. } \frac{1}{b}\log_e\left(\frac{a\,\dot{m}_a + bx}{a\,\dot{m}_a}\right) = \frac{1}{F_1}\log_e\left(\frac{F_2 - F_1\, T_2}{F_2 - F_1\, T}\right) \qquad (2.79)$$

$$\therefore (F_2 - F_1\, T_2)/(F_2 - F_1\, T) = \left(1 + \frac{bx}{a\,\dot{m}_a}\right)^{F_1/b} \qquad (2.80)$$

Eq. (2.80) is the governing equation for the inside temperature distribution of the coach.

2.3 EVALUATION OF COACH INLET AND EXIT CONDITIONS:

(a) CASE -A (without regeneration):

Figures 2.5 (a) and (b) show the non-regenerative cooling system and the process during humidification in the humidifier. Assuming as evaporative cooler efficiency (η) of 0.75, we have:

$$T_i = T_{db} (1 - \eta) + \eta T_{wb} \tag{2.81}$$

where T_{db} (^oC) and T_{wb} (^oC) are the summer design conditions of a particular place for a particular month [22]

Using Carrier's equation,

$$p_v = p_s (T_{wb}) - [p - p_s(T_{wb})] \frac{(T_{db} - T_{wb})}{1547 - 1.44 T_{wb}} \tag{2.82}$$

where the function p_s (T) is given by [23]

$$\log_e \frac{221.2}{p_s(T)} = \left\{7.21379 + (1.1520 \times 10^{-5} - 4.787 \times 10^{-9} (T + 273.16))(T - 210.0)^2\right\} \times \left(\frac{647.31}{(T+273.16)} - 1\right) \tag{2.83}$$

where T is in ^oC and p_s (T) is in bars.

For outside air the specific humidity w_a(kgw/kg of dry air) at the design condition is found from :

$$w_a = 0.622 p_v /(p - p_v) \tag{2.84}$$

$$\Phi_a = \text{relative humidity of ambient air} = p_v/p_s(T_{db}) \tag{2.85}$$

For inlet conditions to coach we have

$$w_2 = 0.622(p_v)_i/[p-(p_v)_i] \tag{2.86}$$

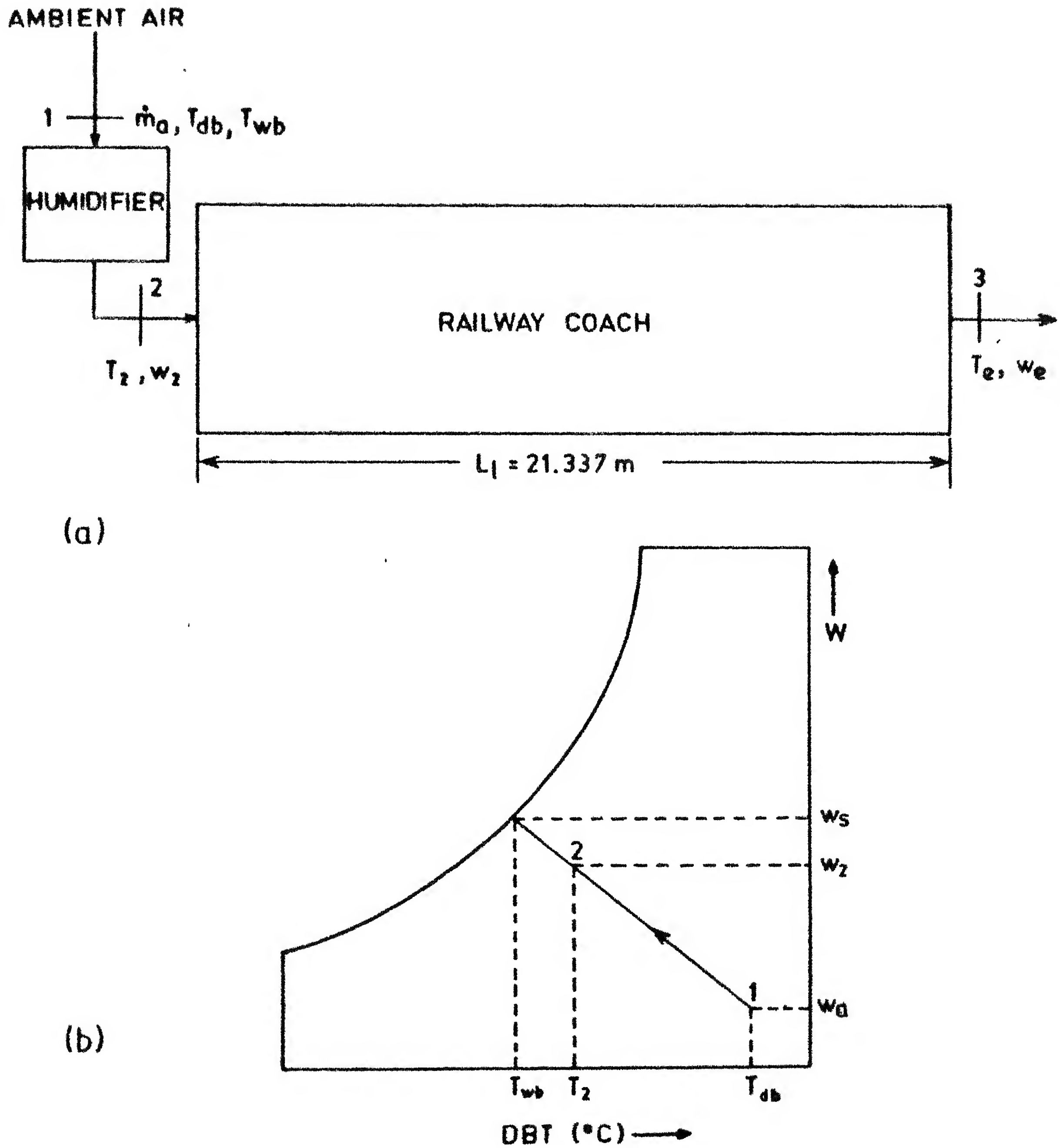

Fig. 2.5. (a) Schematic representation of non-regenerative evaporative cooling system.
(b) Process of humidification of non-regenerative cooling.

$$\Phi_2' = (p_v)_2 / p_s(T_2) \tag{2.87}$$

where $(p_v)_2$ is given by

$$(p_v)_2 = p_s(T_{wb}) - [p - p_s(T_{wb})](T_2 - T_{wb})/(1547 - 1.44\, T_{wb}) \tag{2.88}$$

and Φ_2 = relative humidity of air after humidification in the humidifier.

At coach exit we have

$$w_e = \frac{w''' A_c}{\dot{m}_a} L_1 + w_2 \tag{2.89}$$

Also, $w_e = 0.622\, (p_v)_e / (p - (p_v)_e)$. (2.90)

From Eq. (2.90) we have

$$(p_v)_e = \frac{p\, w_e}{0.622 + w_e} \tag{2.91}$$

and $\Phi_e = (p_v)_e / p_s(T_e)$

(b) CASE-B (with regeneration):

In this case, a fraction of exit air from the coach is recirculated through an indirect contact regenerative heat exchanger having effectiveness ϵ (Fig. 26 (a)). The ambient air gets cooled from state 1 to state $1'$ without change in specific humidity w_a (sensible cooling process) before entering the humidifier. The air is then humidified having process line $1' - 2'$ (Fig. 26 (b)). The inlet air to the coach at state $2'$ leaves it at state 3, a part of which is recirculated. The above process is repeated until steady conditions are achieved.

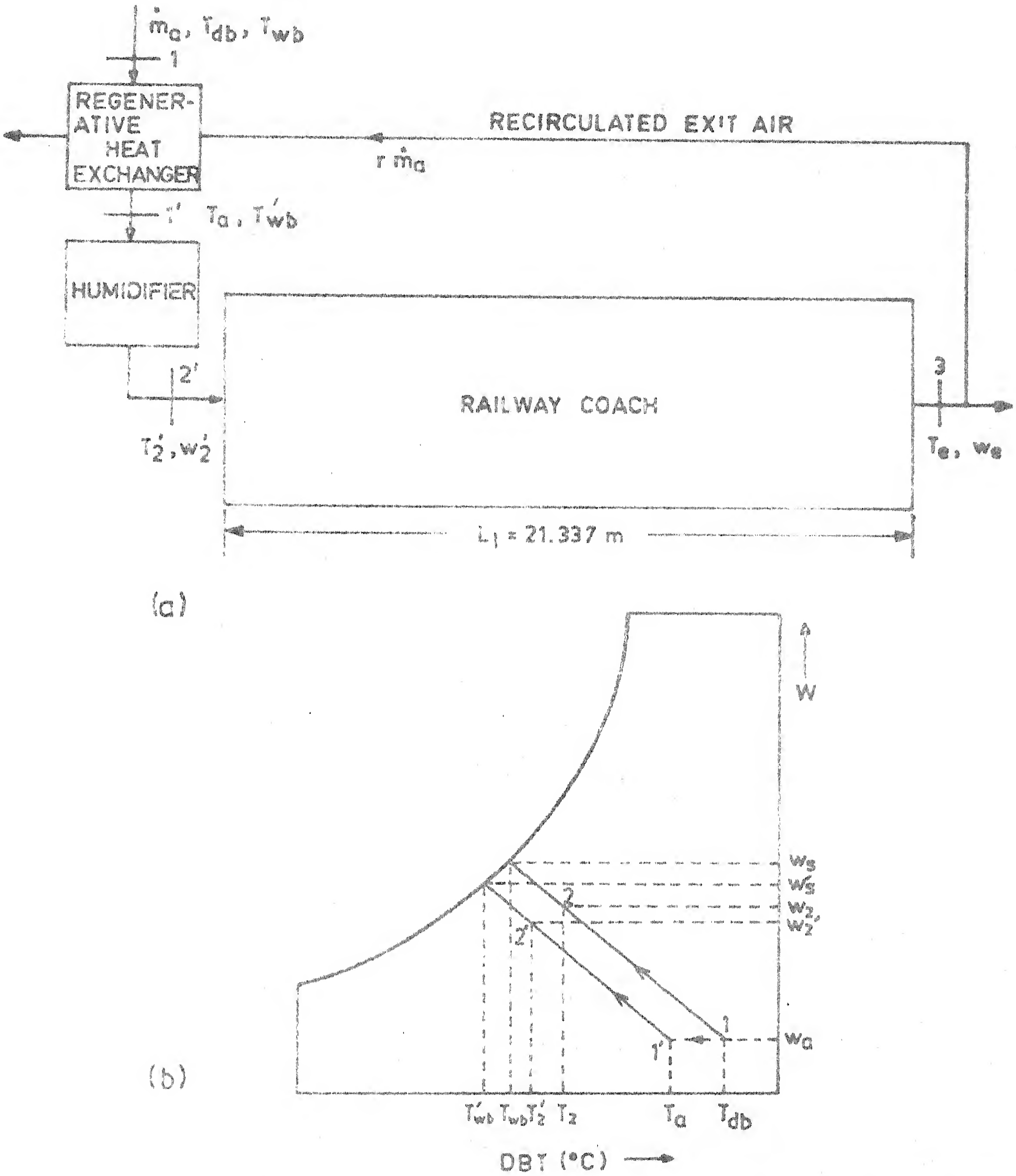

Fig. 2.6 (a) Schematic representation of regenerative evaporative cooling system
(b) Process of humidification for regenerative cooling.

We have:

$$(T_a)_n = T_{db} - r\varepsilon\,(T_{db} - (T_e)_n) \qquad (2.92)$$

where n is the number of iterations under the following imposed constrants:

(i) The temperature difference between the ambient air and the recirculated air should be greater than 3°C for useful regenerative cooling:

$$\text{i.e., } T_{db} - (T_a)_n > 3\ ^\circ C \qquad (2.93)$$

(ii) For steady state:

$$|(T_a)_{n+1} - (T_a)_n| < 0.01\ ^\circ C \qquad (2.94)$$

The method of estimation of $(T_i)_n$ has been described as under:

$$(w_a')_n = w_a \qquad (2.95)$$

$$\text{Also, } (w_a')_n = 0.622\,(p_v')_n / (p - (p_v')_n) \qquad (2.96)$$

From Eqs. (2.84), (2.91) and (2.92) we have

$$(p_v')_n = p_v \qquad (2.97)$$

If $(T_{wb}')_n$ is the wet bulb temperature of air (°C) after sensible cooling in the heat-exchanger, then using Carrier's equation we have

$$(p_v')_n = p_s\,(T_{wb}')_n - \frac{[p - p_s(T_{wb}')_n]((T_a)_n - (T_{wb}')_n]}{1547 - 1.44\,(T_{wb}')_n} \qquad (2.98)$$

$$\text{i.e. } p_s\,(T_{wb}')_n - \frac{[p - p_s(T_{wb}')_n][(T_a)_n - (T_{wb}')_n]}{1547 - 1.44(T_{wb}')_n} - (p_v')_n = 0 \qquad (2.99)$$

which can be put in the form

$$f(T_{wb}')_n = 0 \tag{2.100}$$

This is solved for $(T_{wb}')_n$ using Newton-Raphson method as detailed in Appendix B.

With known (T_{wb}') and $(T_a)_n$, $(T_i)_n$ can be found from the following:

$$(T_i)_n = (T_a)_n \, (1 - \eta) + \eta \, (T_{wb}')_n \tag{2.101}$$

For state 2' we have

$$[(p_v)_2]_n = p_s \, (T_{wb}')_n - \frac{[p - p_s(T_{wb}')_n][(T_i)_n - (T_{wb}')_n]}{1547 - 1.44(T_{wb}')_n} \tag{2.102}$$

From eq. (2.102) we have

$$(w_2')_n = 0.622 \, [(p_v)_2]_n / (p - [(p_v)_i]_n) \tag{2.103}$$

and,

$$(\Phi_2')_n = [(p_v)_2]_n / p_s \, (T_i)_n \tag{2.104}$$

From the known above inlet conditions to the coach and by using the governing equations of heat and mass transfer for the coach, a new value of $(T_e)_n$ was found which was substituted in Eq. (2.88) to get another new value of $(T_a)_n$. This iteration process was continued until Eq. (2.94) is satisfied within the preset limit.

For coach exit putting $x = L_1$ in Eq. (2.3), we have:

$$(w_e)_n = (w''' \, A_c / \dot{m}_a) L_1 + (w_2')_n \tag{2.105}$$

Also,
$$(w_e)_n = \frac{0.622[(p_v)_e]_n}{p - [(p_v)_e]_n} \tag{2.106}$$

From Eq. (2.106) we have:

$$[(p_v)_e]_n = \frac{p\,(w_e)_n}{0.622 + (w_e)_n} \qquad (2.107)$$

$$\Phi_e'(n) = [(p_v)_e]_n \,/\, p_s\,(T_e)_n \qquad (2.108)$$

Thereafter the following quantities were calculated as a final result:

No. of iterations n.

After 'n' iterations the final values are:

$T_a =$,	$w_a' =$,	$\Phi_a' =$,
$T_2 =$,	$w_2' =$,	$\Phi_2' =$,
$T_e =$,	$w_e =$,	$\Phi_e =$,

CHAPTER 3

COMPUTATION OF VARIOUS QUANTITIES

This section deals with the computational details used to determine:

(a) Cooling Load (TR)

(b) Ambient and Coach Conditions.

(c) Water requirement for the humidifier ,

(d) Air washer dimensions of the humidifier and

(e) 'Sensible heat Conversion Rate (SHCR)' and 'Unit Sensible Heat Conversion Rate (USHCR)'

The computational methods for the calculation of the above-mentioned parameters are given below:

(a) Cooling Load (TR):

As the overall heat transfer coefficient U_{sj} is implicity related to x the integration of the governing equation cannot be done for the entire length of the coach. Hence finite element method has been used. The coach has been divided into 23 sections and the total heat load ΔQ_{TOTAL} (kJ/h) through each section has been calculated and summed up to find the grand total heat load Q_{TOTAL}(kJ/h) for the coach. Mathematically:

For $j = 3$:

$$(\Delta Q_{ST})_j = \sum_{s=1}^{2} U_{sj} f_j [(T_{sol})_{sj} - T_m] + \sigma_s f_j \quad (L_1/23) \qquad (3.1)$$

For $j \neq 3$:

$$(\Delta Q_{ST})_j = \sum_{s=1}^{2} U_{sj} f_j [(T_{sol})_{sj} - T_m] \qquad (3.2)$$

where T_m = mean temperature inside the section (^oC) which is given by

$$T_m = (T_{x_i} + T_{x_{i+1}})/2 \qquad (3.3)$$

The heat release ΔQ_R (kJ/h), is found as:

$$Q_R = q''' A_c (L_1/23) \qquad (3.4)$$

The total heat load is calculated as:

$$(\Delta Q_{TOTAL})_i = [\Delta Q_R + \sum_{j=1}^{4} (\Delta Q_{ST})_j]_i \qquad (3.5)$$

Hence the grand total heat load Q_{TOTAL} is :

$$Q_{TOTAL} = \sum_{i=1}^{23} (\Delta Q_{TOTAL})_i \qquad (3.6)$$

The cooling load TR' expressed in tons is:

$$TR' = Q_{TOTAL}/12600 \qquad (3.7)$$

Assuming a safety factor of 1.1 , the design tonnage TR is:

$$TR = 1.1\ TR' \qquad (3.8)$$

The cooling load can also be expressed as

$$TR = [\dot{m}_a c_{pa} (h_e - h_2)]/12600 \qquad (3.9)$$

where h_e = specific enthalpy of air at exit (kJ/kg dry air).

h_2 = specific enthalpy of air at inlet (kJ/kg dry air).

(b) Ambient and coach conditions:

The calculation of ambient, coach inlet and coach exit conditions have already been discussed in sec. 2.3. To determine the temperature distribution inside the coach an iteration process is followed wherein at each section the following procedure is used:

For any section 'i', we have:

(a) For the 1st iteration:

$$T_{x_i} = T_i \tag{3.10}$$

At section 1 (i.e., at inlet) we have:

$$x_1 = 0; \quad T_{x_1} = T_2 \tag{3.11}$$

Assuming the above, the values of U_{sj} are calculated and and used in the governing heat transfer equation for temperature distribution inside the coach to find the temperature T at section (i + 1). Thus

$$T_{x_{i+1}} = T_{i+1} \tag{3.12}$$

(b) For the succeeding iterations:

A mean temperature, T_m, for section 'i' is calculated as:

$$T_m = (T_i + T_{i+1})/2 = (T_{x_i} + T_{x_{i+1}})/2 \tag{3.13}$$

Using the above value of T_m, the new values of U_{sj} are calculated to obtain the new temperature at section (i+1). Hence,

$$T_{x_{i+1}} = T'_{i+1} \tag{3.14}$$

The iteration continues until the following constraint $T_{i+1} - T_i < 0.01$ is satisfied.

In this above manner, the values of T_{x_i} are calculated for all the sections. To calculate the humidity variation inside the coach, we use the governing equation of mass transfer. The rise in temperature $\Delta T(^oC)$ inside the coach is given by

$$\Delta T = T_e - T_2 \tag{3.15}$$

The average temperature T_{av} (^oC) inside the coach is given by

$$T_{av} = \frac{T_2 + T_e}{2} \tag{3.16}$$

The relative humidity of air, Φ_i at any section 'i' is given by

$$\Phi_i = (p_v)_i / p_s (T_i) \tag{3.17}$$

where
$$(p_v)_i = \frac{p\ w_i}{0.622 + w_i} \tag{3.18}$$

(c) Water requirement for the humidifier:

The water requirement ($\dot{m}_w$) for the humidifier in kg/h can be computed as follows:

$$\dot{m}_w = \dot{m}_a (w_2 - w_a) \tag{3.19}$$

To calculate the air washer dimensions we use the following procedure:

Assuming a face velocity of air V_{face} (m/s) through the air washer one gets:

$$\eta = 1 - e^{-Z} \tag{3.20}$$

where, η = humidifier or air washer efficiency.

and
$$Z = \frac{h_D \ A_v \ V_{aw}}{\dot{m}_a} \tag{3.21}$$

With $h_D A_v$ = mass transfer coefficient (kgw/h-m^3-(kgw/kg dry air)).

V_{aw} = volume of the air washer (m^3).

From Eq. (3.20) we have:

$$Z = -\log_e (1 - \eta) \tag{3.22}$$

From Eqs. (3.21) and (3.22) we have:

$$V_{aw} = -\dot{m}_a \ \log_e (1 - \eta)/h_D A_v \tag{3.23}$$

For the outside conditions of air, the specific volume of moist air v(m^3/kg dry air) is given by

$$v = 287.2 \ (T_{db} + 273.16)/[(p - p_v) \times 10^5] \tag{3.24}$$

If Q_v is the volume flow rate of air (m^3/h) through the air washer then

$$Q_v = \dot{m}_a \ v \tag{3.25}$$

To calculate the required length L_{aw} (m) and face area A_{aw} (m^2) of the air washer we use:

$$A_{aw} = Q_v /(V_{face} \times 3600) \tag{3.26}$$

and
$$L_{aw} = V_{aw}/ A_{aw} \tag{3.27}$$

Thus the above quantities are calculated as:

WITHOUT REGENERATION:

$$x_1 = 0;\ T_2 = T_{x_1}, \qquad x_1 = L_1;\ T_e = T_{x_{24}}, \qquad T = T_e - T_2$$

$$T_{av} = \frac{T_e + T_2}{2}, \qquad \dot{m}_w = \dot{m}_a\,(T_e - T_2) \qquad \Phi_i = (p_v)_i / p_s(T_i)$$

with $$(p_v)_i = \frac{p\,w_i}{0.622 + w_i}$$

WITH REGENERATION:

$$x_1 = 0;\ T_2' = T_{x_1}, \qquad x_1 = L_1; (T_e)_n = T_{x_{24}}, \qquad T = (T_e)_n - (T_2')_n$$

$$T_{av} = \frac{(T_e)_n + (T_2')_n}{2} \qquad \dot{m}_w = \dot{m}_a[(T_e)_n - (T_2')_n)]$$

$$(\Phi_i')_n = [(p_v')_i]_n / p_s(T_i)_n$$

with $$[(p_v')_i]_n = \frac{p\,(w_i)_n}{0.622 + (w_i)_n}$$

(d) SHCR AND USHCR:

The performance of the humidifier at various places with different design conditions can be compared by use of the performance indices [24], 'Sensible Heat Conversion Rate (SHCR)' and 'Unit Sensible Heat Conversion Rate (USHCR)' defined as:

$$\text{SHCR} = \dot{m}_a\,(c_{pm_1} T_{b_1} - c_{pm_2} T_{b_2}) \quad (\text{kJ/h}) \qquad (3.28)$$

and $$\text{USHCR} = \text{SHCR}/T_{wbd} \quad (\text{kJ/h-}^{\circ}\text{C}) \qquad (3.29)$$

where c_{pm_1} = specific heat of moist air at inlet of humidifier (kJ/kg - °C)

c_{pm_2} = specific heat of moist air at exit of humidifier (kJ/kg - °C)

T_{b_1} = temperature of air at inlet of humidifier (°C).

T_{b_2} = temperature of air at exit of humidifier (°C).

T_{wbd} = wet-bulb depression (°C).

The specific heat c_{pm} (kJ/kg - °C) of moist air is given by

$$c_{pm} = c_{pa} + 1.884\ w \tag{3.30}$$

For c_{pa} = 1.004, we have

$$c_{pm} = 1.004 + 1.884\ w \tag{3.31}$$

WITHOUT REGENERATION:

$$c_{pm_1} = 1.004 + 1.884\ w_a \quad ; \quad T_{b_1} = T_{db} \tag{3.32}$$

and $$c_{pm_2} = 1.004 + 1.884 w_2 \quad ; \quad T_{b_2} = T_2 \tag{3.33}$$

WITH REGENERATION:

$$c_{pm_1} = 1.004 + 1.884\ w_a' \quad ; \quad T_{b_1} = T_a \tag{3.34}$$

$$c_{pm_2} = 1.004 + 1.884\ w_2' \quad ; \quad T_{b_2} = T_2' \tag{3.35}$$

3.1) INPUT PARAMETERS:

The input data to the computer program for various places on different routes is shown in Table 3.1.

TABLE 3.1

LONGITUDES AND LATITUDES OF IMPORTANT STATIONS ON DIFFERENT ROUTES

ROUTE	PLACE	LATITUDE (°)	OUTSIDE DESIGN CONDITIONS T_{db} (°C)	T_{wb} (°C)	Ψ_1 (°)	Ψ_2 (°)	LONGITUDE (EAST) (°)	(')
SE	Delhi	29.0	40.4	23.9	135.0	45.0	77.0	12.0
SE	Kanpur	27.0	41.2	21.5	135.0	45.0	80.0	30.0
SE	Allahabad	25.0	41.7	25.0	135.0	45.0	81.0	53.0
SE	Patna	26.0	37.9	26.7	135.0	45.0	85.0	1.0
SE	Jamshedpur	23.0	39.4	28.4	135.0	45.0	87.0	1.0
S	Delhi	29.0	40.4	23.9	90.0	90.0	77.0	12.0
S	Chandigarh	31.0	40.1	23.9	90.0	90.0	77.0	10.0
S	Bhopal	23.0	40.2	23.2	90.0	90.0	78.0	1.0
S	Nagpur	21.0	42.6	24.5	90.0	90.0	79.0	3.0
S	Hyderabad	17.0	39.5	26.6	90.0	90.0	77.0	55.0
SW	Delhi	29.0	40.4	23.9	45.0	135.0	77.0	12.0
SW	Jodhpur	26.0	40.8	25.3	45.0	135.0	73.0	1.0
SW	Jaipur	27.0	40.8	21.7	45.0	135.0	76.0	30.0
SW	Ahmedabad	23.0	41.5	29.0	45.0	135.0	72.0	38.0
SW	Baroda	22.0	40.3	29.1	45.0	135.0	72.0	38.0

The outside design conditions indicated in Table 3.1 are for the summer month of May. The longitude of the standard meridiam is taken as $82^\circ 30'$ E. The declination angle and the equation of time have been obtained for May 21. The calculations for hour angle has been done for Indian Standard Time (I.S.T.) of 12.00 noon. The geometric dimensions of the coach have been taken from Appendix. The coach dimensions were obtained from drawing supplied by RDSO, Lucknow. Thus the final input values are:

$d = 20^\circ$, equation of time $= 3^m\ 37^s$, IST=12:00 noon

$\alpha_1 = 0.50$, $\alpha_2 = 0.40$, $\rho_{gr} = 0.20$,

$A = 1103\ W/m^2$, $B = 0.190$ $C = 0.121$

$p = 1.0132$ bar, and $\eta = 0.75$.

The values of r_{cs} for glass window have been calculated as detailed in Appendix C. The effect of regeneration on evaporative cooling has been studied by taking the following values of ε and r :

$\varepsilon = 0.60,\ 0.70,\ 0.80$

$r = 0.50,\ 0.65,\ 0.80.$

The effect of moisture release M_p has been studied by taking values of M_p as 0.050, 0.100, 0.150 and 0.200 kg of moisture/kg dry air.

3.2 COMPUTER PROGRAM:

The computer program for the various calculations of both non-regnerative and regenerative cooling has been given in Appendix D. The function subprograms used are TIME, AG, PV, PS, AT, FSS, FSG, REFL and the subroutines are NEWTON, FANGER and WETTEM. TIME returns the value of 1 if L.A.T. is forenoon, 2 if L.A.T. is afternoon, 3 if L.A.T. is noon. Depending on this value, the values of γ_{sj} are calculated by the functions of program AG. PV calculates the partial pressure of water vapour in bars using Carriers equation and PS calculates the value of p_s (T) in bars AT calculates the value of δ_{sj} while FSS and FSG calculate the values of $(F_{ss})_{sj}$ and $(F_{sg})_{sj}$ respectively. REFL returns the value of r_{cs} for glass while NEWTON is a subroutine to calculate $(T_{wi})_{sj}$ by Newton-Raphson method to an accuracy of 1%. The subroutine FANGER gives the value of convective heat transfer coefficient over the human body from which comfort velocity V_{cv}(m/s) is determined. Finally, the subroutine WETTEM uses Newton-Raphson iteration to find T'_{wb} for the regenerative evaporative cooling system.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 EFFECT OF VARIOUS PARAMETERS:

4.1.1 Effect of air flow rate on TR, ΔT and T_{av} (without regeneration):

Figures 4.1 and 4.2 show the effect of air flow rate on TR and ΔT. It is seen that with an increase in air flow rate, the tonnage increases by about 8% due to a decrease in inside temperature of the coach as ΔT for higher mass flow rates is less. With increase in the inside heat transfer coefficient for free convection or forced convection, the tonnage TR and ΔT increase due to greater heat transfer to the coach. It is, however, found that free convection gives higher tonnage than forced convection due to small velocity. Hence the temperature inside the coach is less for forced convection as compared to the free convection for the same inlet temperature of air.

Figures 4.3, 4.4 and 4.5 exhibit the effects of air flow rate on the average temperature inside the coach. The results have been presented for various places of different routes at their respective design ambient conditions for summer. The average temperature inside the coach(T_{av}) decreases invariably with increase in air flow rate. The temperatures inside the coach are in the range of 30 - 35^{o}C which is not very far from the comfort conditions.

4.1.2 Effect of train velocity on TR:

Figure 4.6 shows the effect of train velocity on TR. It decreases by about 1 to 3 % with an increase in train speed from 60 to 120 km/h. This is due to the fact that with higher train velocity, h_o increases rapidly than the overall heat-transfer coefficient U due to which the sol-air temperature gets decreased. Hence their net effect causes decrease in TR. The inside temperature at higher velocity is found to be lower than that at lower velocity of the train. This has been observed for the regenerative case as well.

4.1.3 Effect of regeneration:

a) Effect of recirculation:

Figures 4.9 to 4.11 show the effect of recirculation on TR, ΔT and T_{av}. Increased recirculation renders the lower temperature inside the coach as compared to the non-regenerative case. The tonnage for regenerative cooling is therefore higher than that of the non-regenerative case. Further, the higher recirculation causes better comfort conditions inside the coach.

b) Effect of heat exchanger effectiveness:

The higher heat-exchanger effectiveness also produces the same effect as increased recirculation as shown in Figs. 4.12 to 4.14. Here two the temperatures inside the coach are lower than that of the non-regenerative case. However, it is found that increasing recirculation is more effective in bringing down the temperatures inside the coach

than increasing heat exchanger effectiveness. This is supported by the fact that recirculation decreases the temperature by about 4.7% whereas heat exchanger effectiveness decreases the same by only 3%.

4.1.4 Effect of moisture release:

Figures 4.15 and 4.16 show the effect of moisture release on tonnage and temperature distribution inside the coach. The higher the moisture release, the lower the temperature inside the coach. This is due to the fact that the sensible heat of air is partly used by moisture for its latent heat of vaporization causing decrease in the air temperature. But the tonnage increases by about 2.3% as the coach temperature is lowered.

4.1.5 Effect of air flow rate on $\dot{m}_w$:

With increased air flow rate the water requirement for the humidifier increases linearly as shown in Figs. 4.17 and 4.18. The temperature at inlet to humidifier decreases by about 0.2°C depending upon the rate of recirculation. For the same evaporative cooling efficiency (η = 0.75), the specific humidity at exit of humidifier is less compared to that without regeneration. Hence, the value of $\dot{m}_w$ is less for the regenerative process. It is to be noted that the regenerative process requires less water supply and renders better inside conditions as compared to non-regenerative case.

4.1.6 Effect of air flow rate on SHCR and USHCR:

Figure 4.19 shows that the performance indices SHCR and USHCR increase linearly with air flow rate. The water

requirement $\dot{m}_w$ and the values of SHCR and USHCR for various places with given design ambient conditions for summer are presented in Table 4.1 for an air flow rate of 10,000 kg/h. It is observed from Table 4.1 that the indices of performance SHCR and USHCR decrease with increase in the relative humidity of the ambient air. So , for effective evaporative cooling, the relative humidity of the ambient air should be as low as possible. To get comfort conditions inside the coach the air circulation rate should not be less than 10,000 kg/h. However, increase in air flow rate would increase the space required for the humidifier, the size of the blower and other components. Therefore, it is suggested that the air supply should be kept in the range of 10,000 to 15,000 kg/h.

The computed values of comfort conditions inside the coach for various mass flow rates with regeneration ($\varepsilon = 0.60, r = 0.50$) for Kanpur are presented in Table 4.2. The required air-washer dimensions are also indicated for a face velocity of 2.4 m/s and quantity $h_D A_v$ taken to be 8000 kgw/h-m^3- (kgw/kg dry air). It is easily seen from Tables 4.1 and 4.2, that regeneration gives lower inlet and exit temperature of the coach compared to the non-regenerative case for Kanpur. The humidifier dimensions lie within the space being available underneath a coach (as per the RDSO's information).

TABLE 4.1

VALUES OF $\dot{m}_w$ AND PERFORMANCE INDICES FOR VARIOUS PLACES

(WITHOUT REGENERATION)

S. No.	Route	Place	Ambient design conditions T_{ab} (°C)	T_{wb} (°C)	Φ_a	$\dot{m}_w$ (kg/h)	SHCR (kJ/h)	USHCR (kJ/h°C)	Temperature at inlet of coach (°C)	Temperature at exit of coach (°C)
1.	SE	Delhi	40.4	23.9	0.25	51.71	1,24,416	7540	28.0	36.1
2.	SE	Kanpur	41.2	21.5	0.16	61.20	1,47,508	7487	26.4	35.1
3.	SE	Allahabad	41.7	25.0	0.26	52.49	1,25,646	7756	29.2	37.5
4.	SE	Patna	37.9	26.7	0.42	35.54	85,116	7600	29.5	37.1
5.	SE	Jamshedpur	39.4	28.4	0.44	35.10	83,360	7578	31.2	38.5
6.	S	Chandigarh	40.1	23.9	0.26	50.79	1,24,660	7694	28.0	36.1
7.	S	Bhopal	40.2	23.2	0.23	53.16	1,27,438	7496	27.5	35.7
8.	S	Nagpur	42.6	24.5	0.22	56.75	1,36,524	7542	29.0	37.4
9.	S	Hyderabad	39.5	26.6	0.37	40.87	98,140	7608	29.8	37.4
10.	SW	Jodhpur	40.8	25.3	0.29	48.81	1,16,806	7536	29.2	37.6
11.	SW	Jaipur	40.8	21.7	0.18	59.39	1,42,874	7480	26.5	35.4
12.	SW	Ahmedabad	41.5	29.0	0.40	39.92	9,55,10	7640	32.1	39.9
13.	SW	Baroda	40.3	29.1	0.44	35.82	8,56,06	7644	31.9	39.4

TABLE 4.2

COACH CONDITIONS AND AIR-WASHER DIMENSIONS FOR KANPUR (T_{db} = 41.2 °C, T_{wb} = 21.5 °C) WITH REGENERATION

T_a (°C)	T'_{wb} (°C)	Φ_a	η	$\dot{m}_a$ (kg/h)	T'_2 (°C)	Φ'_2	T_e (°C)	Φ_e	V_{cv} (m/s)	L_{aw} (m)	A_{aw} (m^2)
8.8	20.8	0.18	0.75	5000	25.3	0.75	33.3	0.50	0.88	1.67	0.52
7.7	20.5	0.20	0.75	10,000	24.8	0.75	29.4	0.60	0.78	1.68	1.03
7.2	20.3	0.20	0.75	15,000	24.5	0.77	27.9	0.65	0.35	1.68	1.55
7.0	20.2	0.20	0.75	20,000	24.4	0.78	27.0	0.68	0.24	1.69	2.06

The water-requirement for the humidifier for Kanpur assuming a service duration of 6 hours is found to be 370 litres with no regeneration, whereas for a regenerative evaporative cooling system (ε = 0.60, r = 0.50), the same comes out to be only 305 litres of water. Hence the water consumption is less for regenerative system in addition to the advantage of better comfort conditions inside the coach.

4.2 EXPERIMENTAL RESULTS:

To study the temperature distribution inside the coach experimentally, a coach model was fabricated from aluminium sheet with a ratio of 1:20 compared to the dimensions of the prototype railway coach. The model was kept inside a wind tunnel and hot air was blown across it. The temperature of the hot air was maintained at the actual ambient conditions of Kanpur during summer, (T_{db} = 41.2°C). The air velocity inside the wind tunnel was used to simulate the actual moving train. The air flow rate through the coach was measured by calibrated rotameter. A heating coil was used to simulate the heat release from persons. The experimental set-up is shown in Fig. 4.20. Four calibrated thermocouples were used to measure the temperatures of air at various points inside the coach and the ambient air temperature. The thermocouples were connected to the direct temperature indicator potentiometer. The results are shown in Fig. 4.21 where the dimensions of the experimental set-up is also shown. The variation in temperature inside the coach is linear which is similar to the predicted nature of temperature variation. However, the temperature increases sharply in the initial section of the coach. This is due to the fact that the temperature of the supply air at inlet to the coach is about 22°C which increases sharply due to the heat release mainly because of high thermal conductivity of the aluminium coach model.

4.3 PROPOSED SYSTEM:

Figure 4.22 gives as schematic representation of the proposed evaporative cooling system for the actual railway coach. Water for the evaporative cooling system is taken from the main supply line at the station. The stored water is pumped through the spray nozzles of the humidifier and the humidified cooled air is passed through the eliminator to remove dust and water droplets. This air is then introduced into the coach to produce comfort conditions. In the actual case, to maintain better comfort conditions, the humidified air should be supplied to passengers directly through grilles. This analysis may be regarded as the extension of the present work.

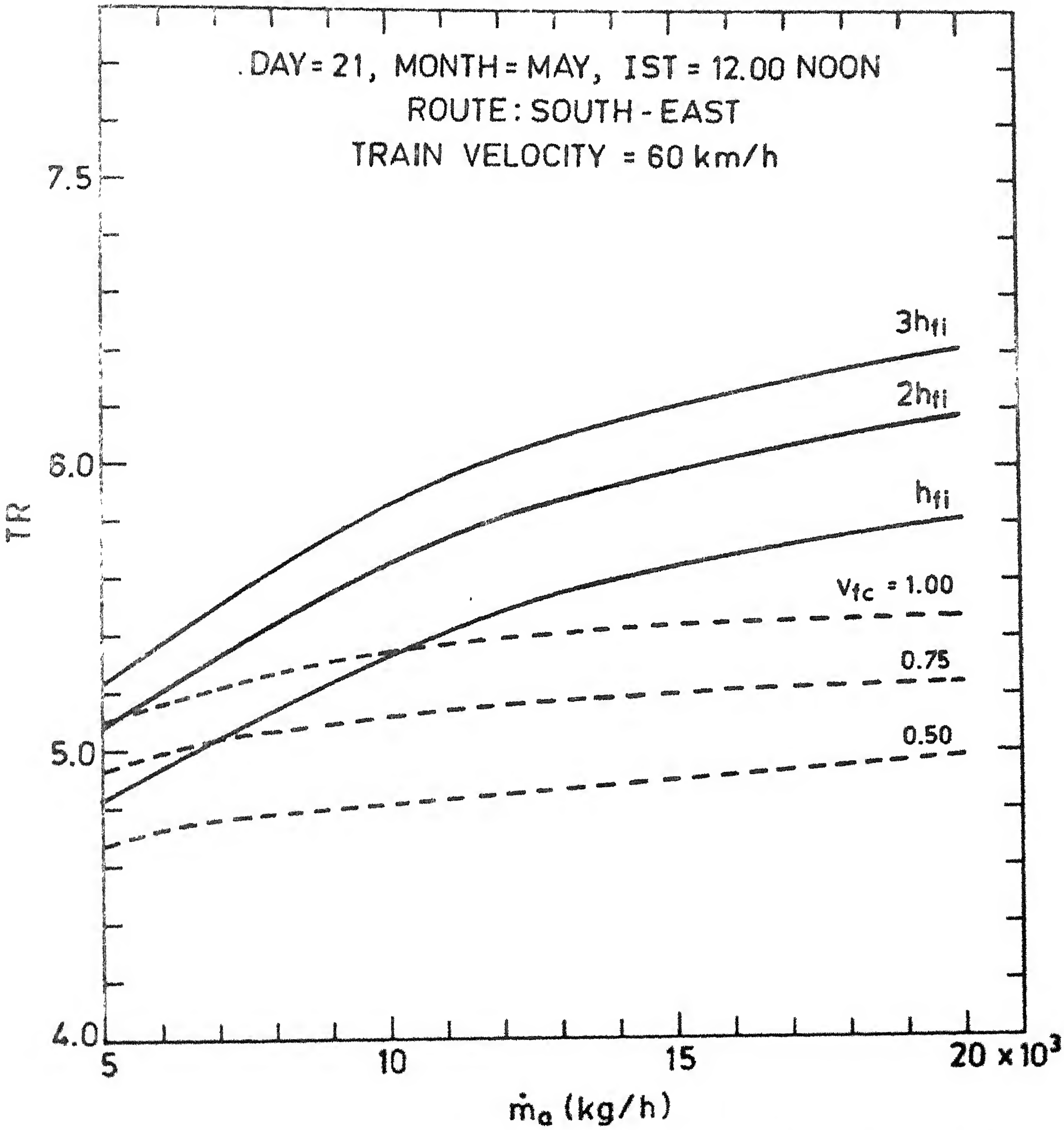

Fig. 4.1. Variation in TR with air flow rate without regeneration (Place - Delhi).

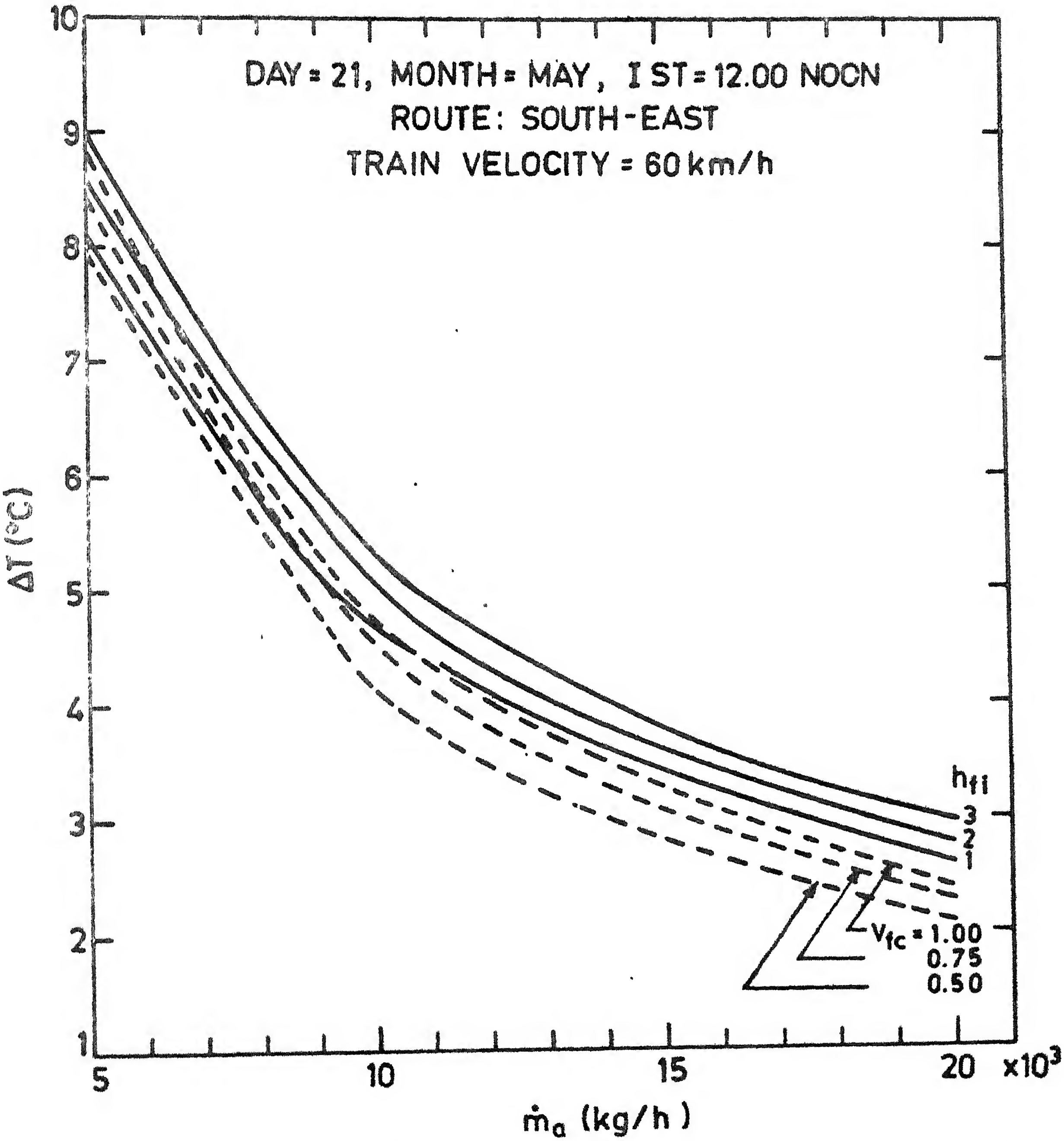

Fig.4.2. Variation in ΔT with air flow rate without regeneration (Place - Delhi).

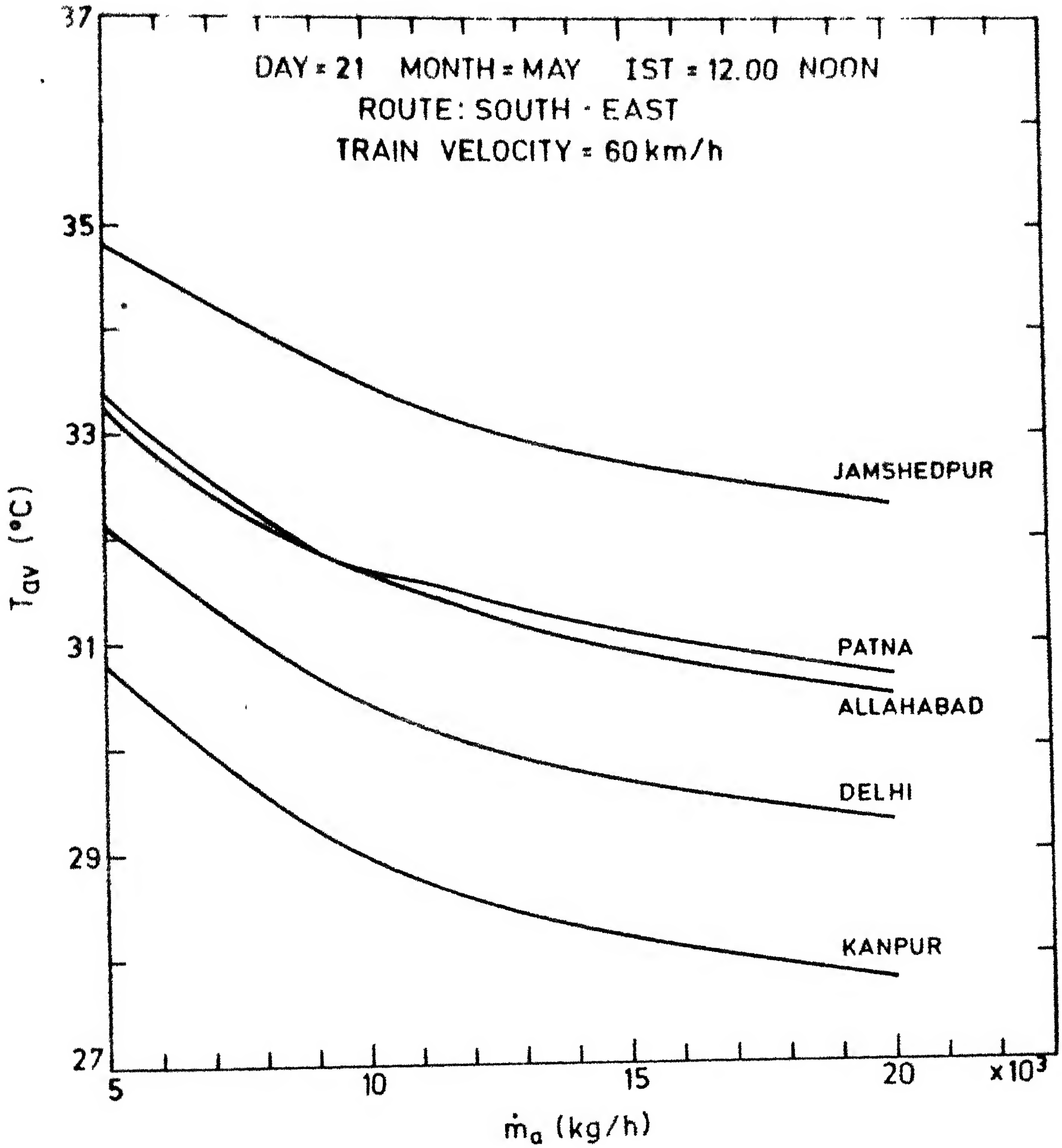

Fig.4.3 Variation in T_{av} with air flow rate for different places without regeneration.

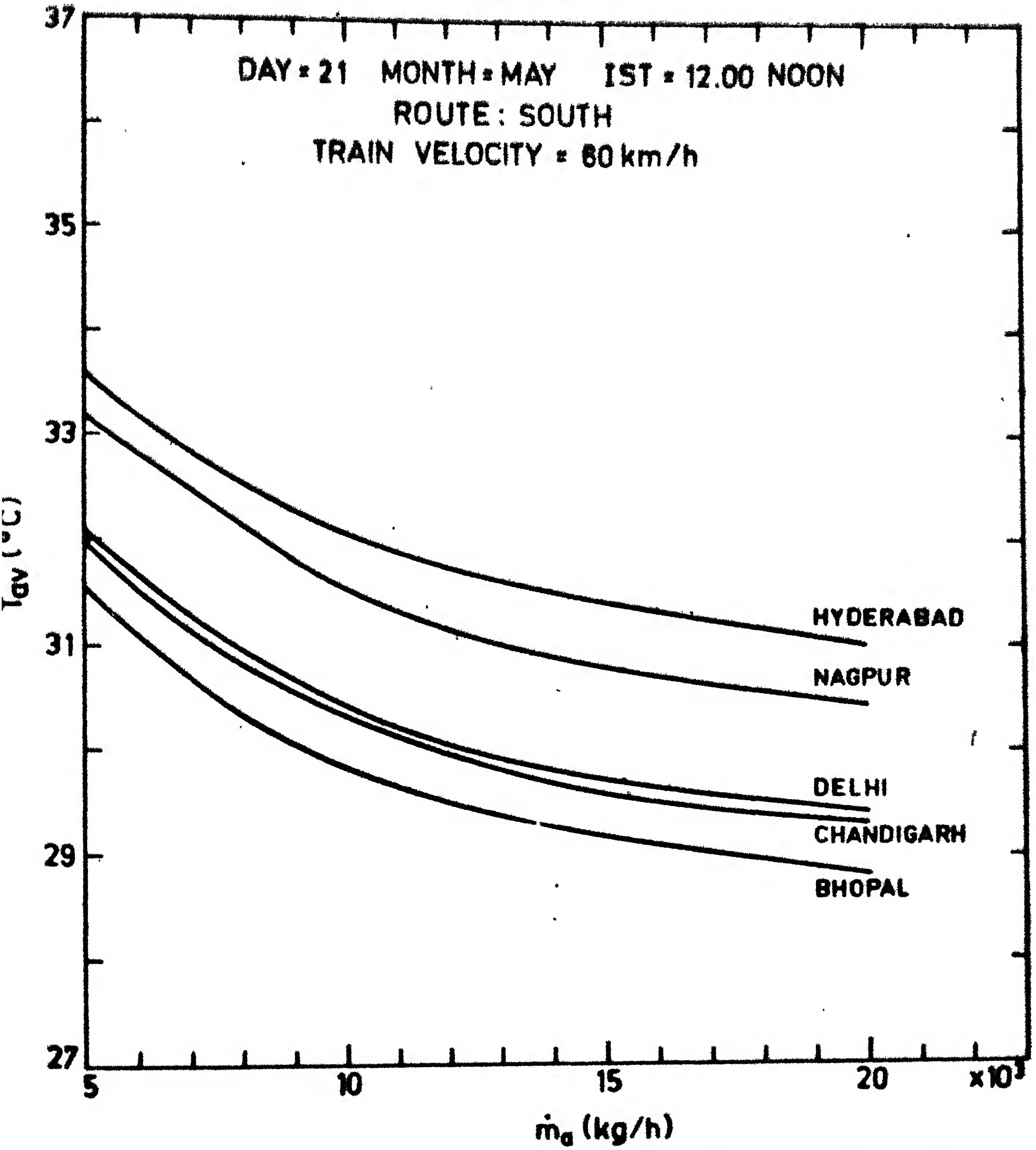

Fig.4.4. Variation in T_{av} with air flow rate for different places without regeneration.

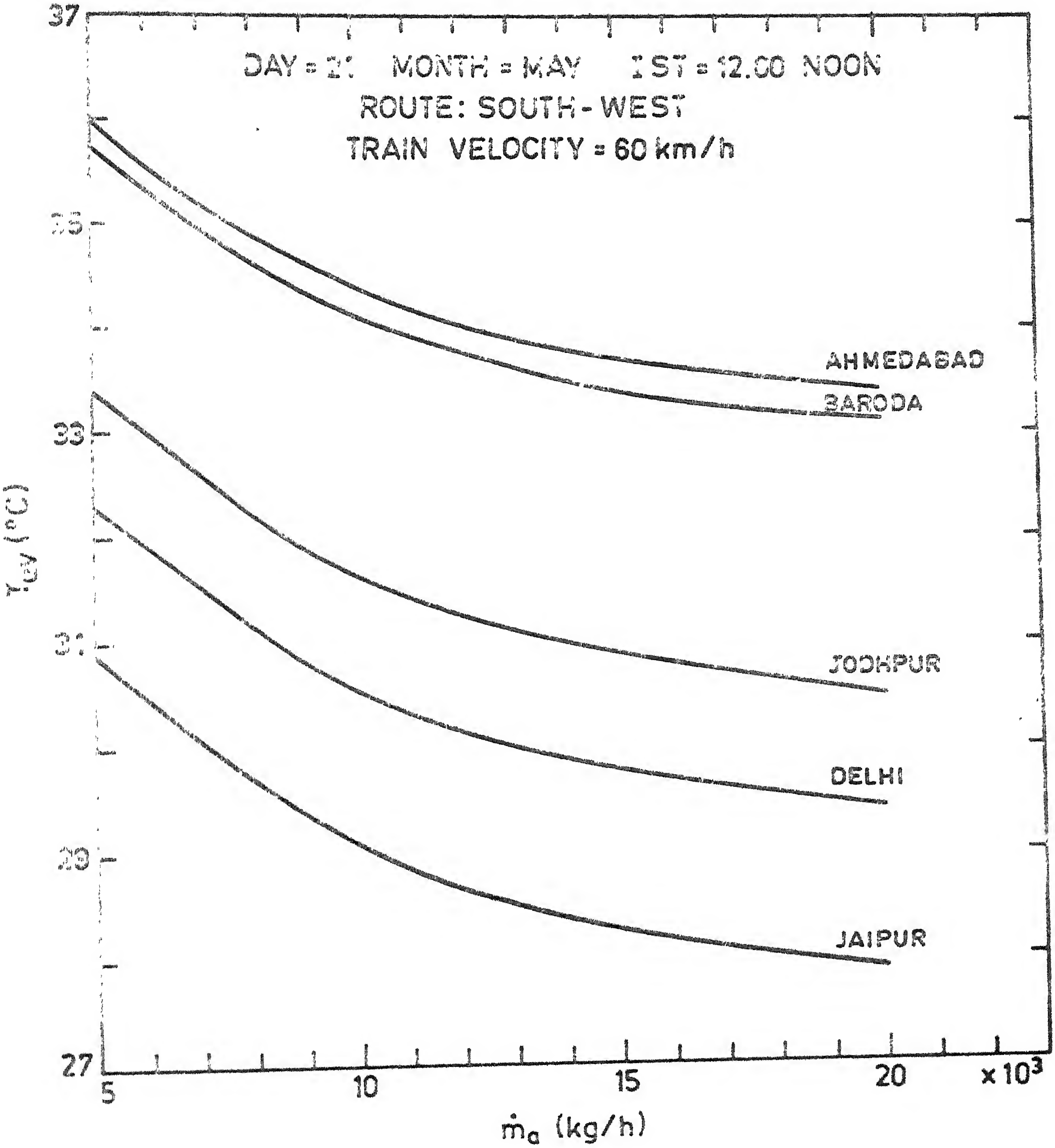

Fig.4.5. Variation in T_{av} with air flow rate for different places without regeneration.

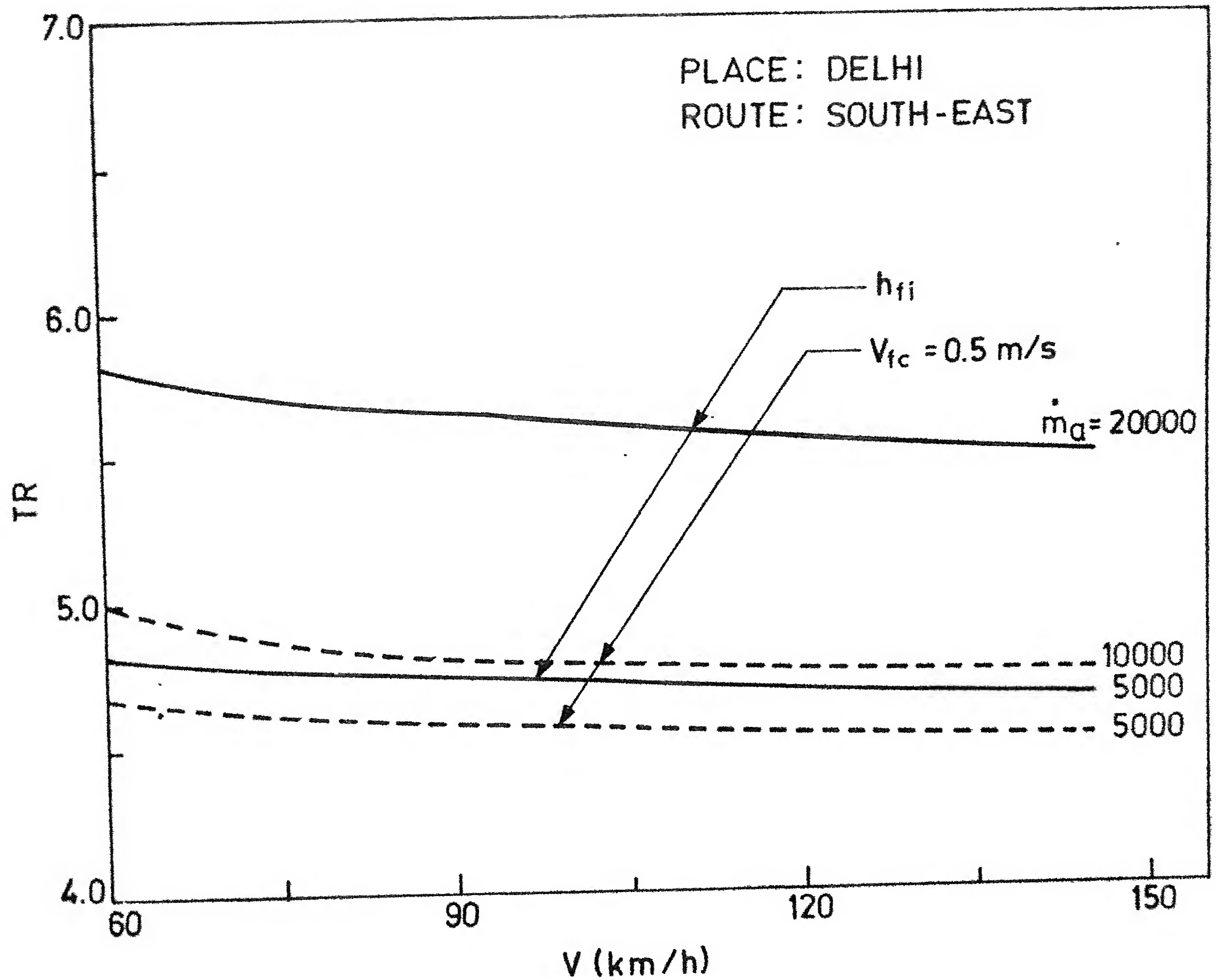

Fig.4.6. Variation in tonnage with train velocity.

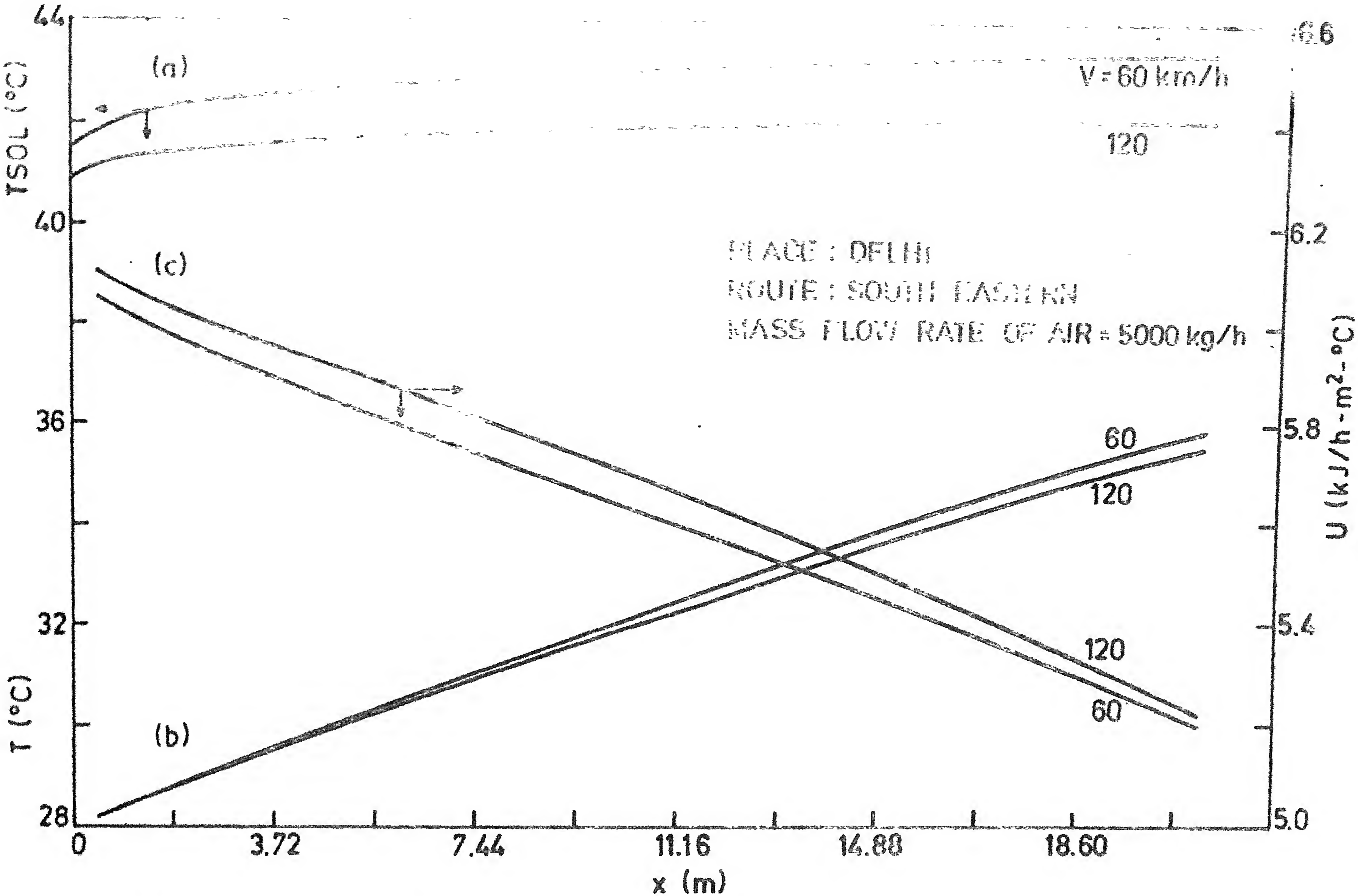

Fig.4.7. Variation with coach velocity of (a) SOL-Air temperature over side wall length (b) inside coach temperature and (c) overall HT transfer coefficient of side wall.

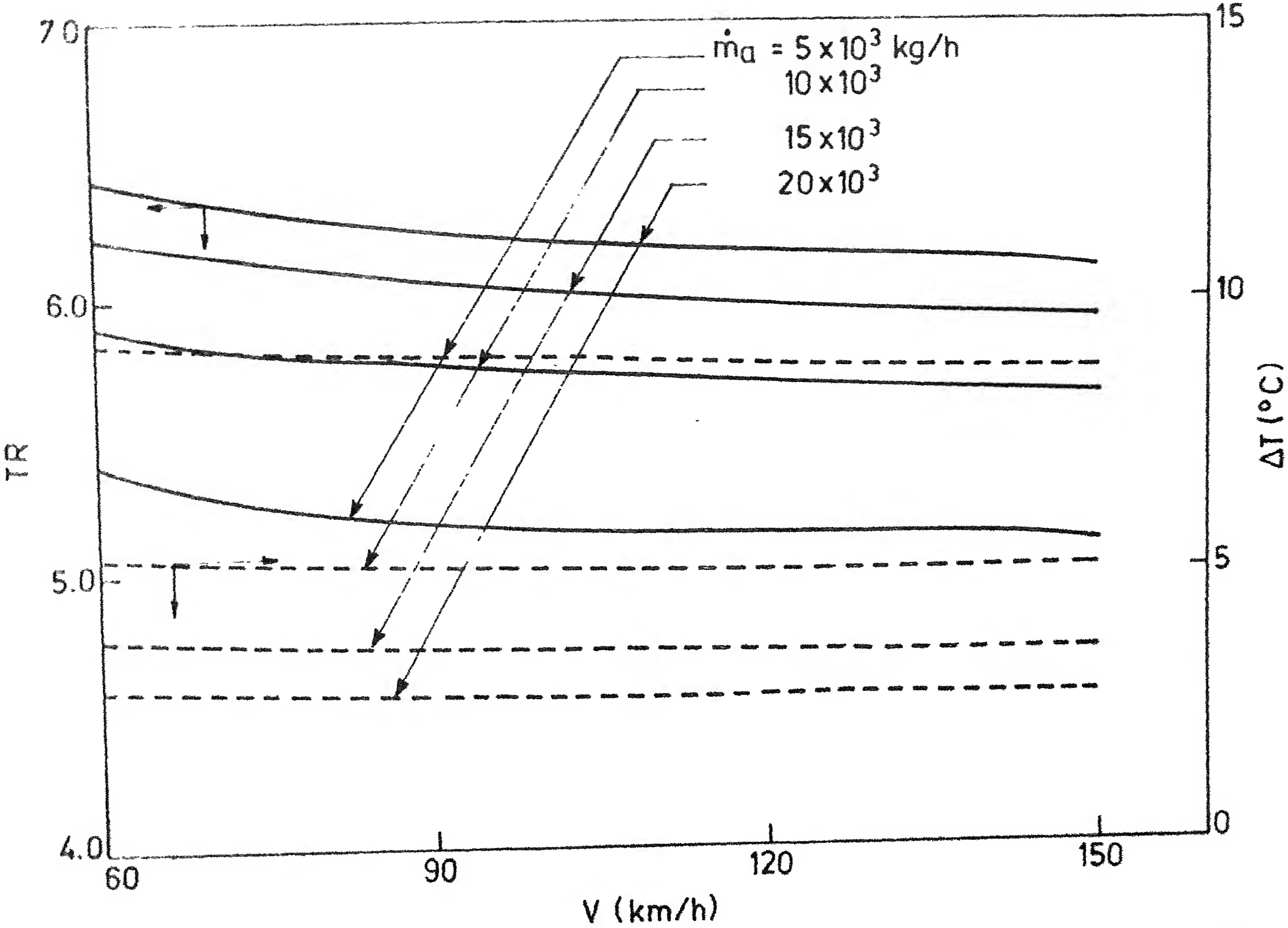

Fig.4.8. Variation in TR and ΔT with train velocity for various air flow rates with regeneration ($\varepsilon = 0.60$, $\gamma = 0.50$) (Place - Kanpur).

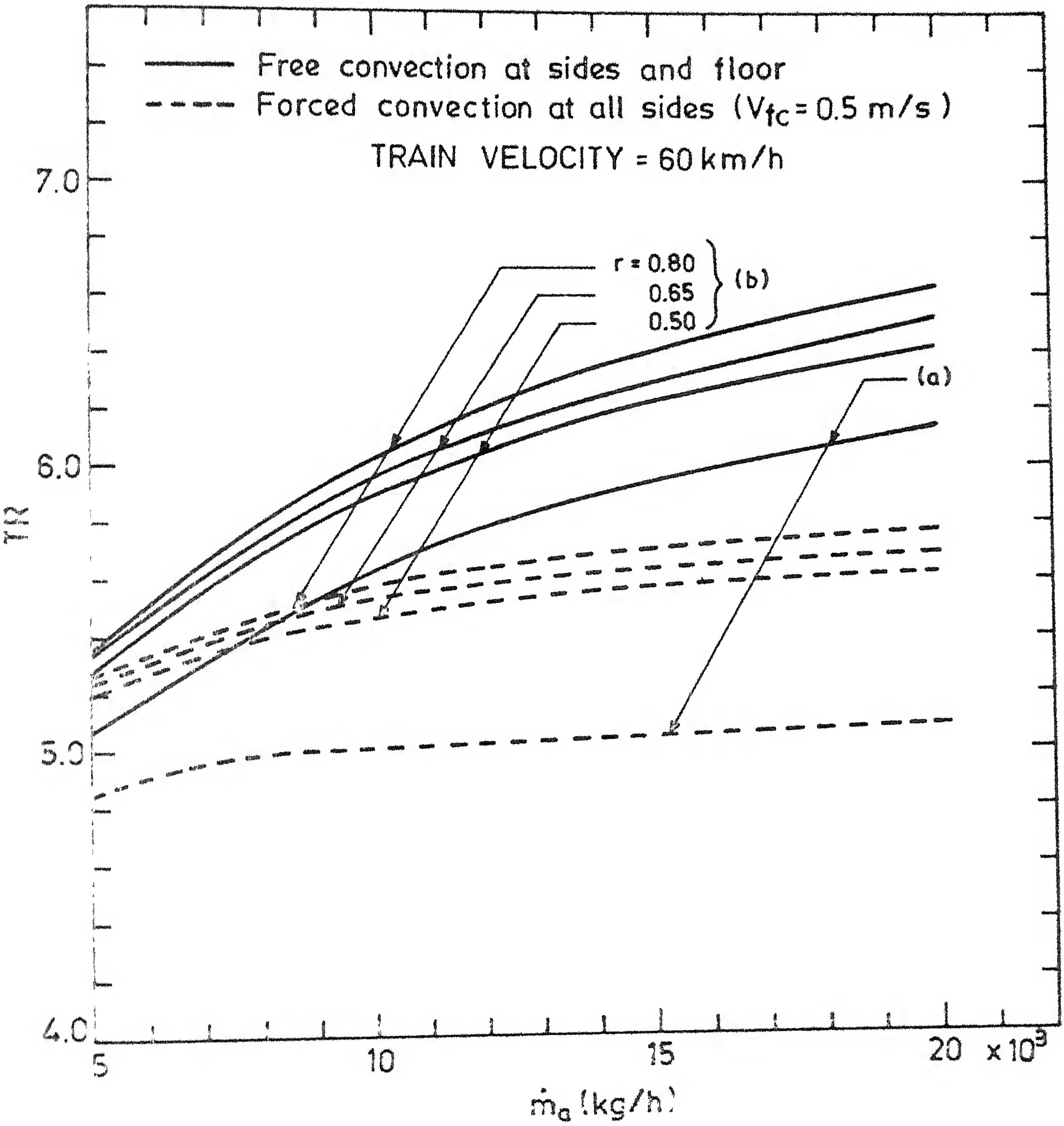

Fig.4.9 Variation in TR with air flow rate for (a) without regeneration and (b) with regeneration using exit air (heat exchanger effectiveness = 0.60). Place - Kanpur).

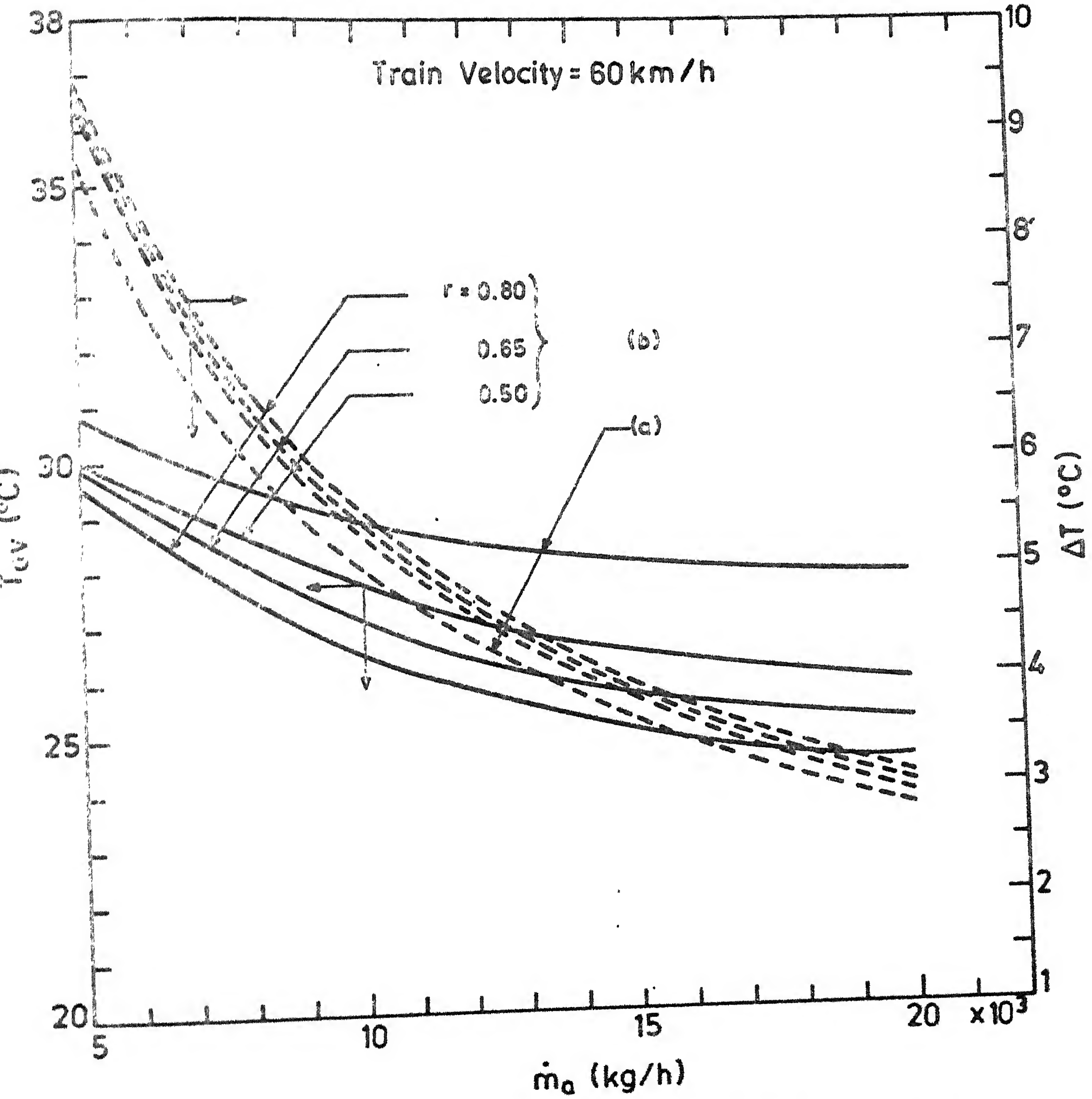

Fig. 4.10. Variation in Tav and ΔT with air flow rate for (a) without regeneration and (b) with regeneration using exit air (heat-exchanger effectiveness = 0.60) (Place - Kanpur).

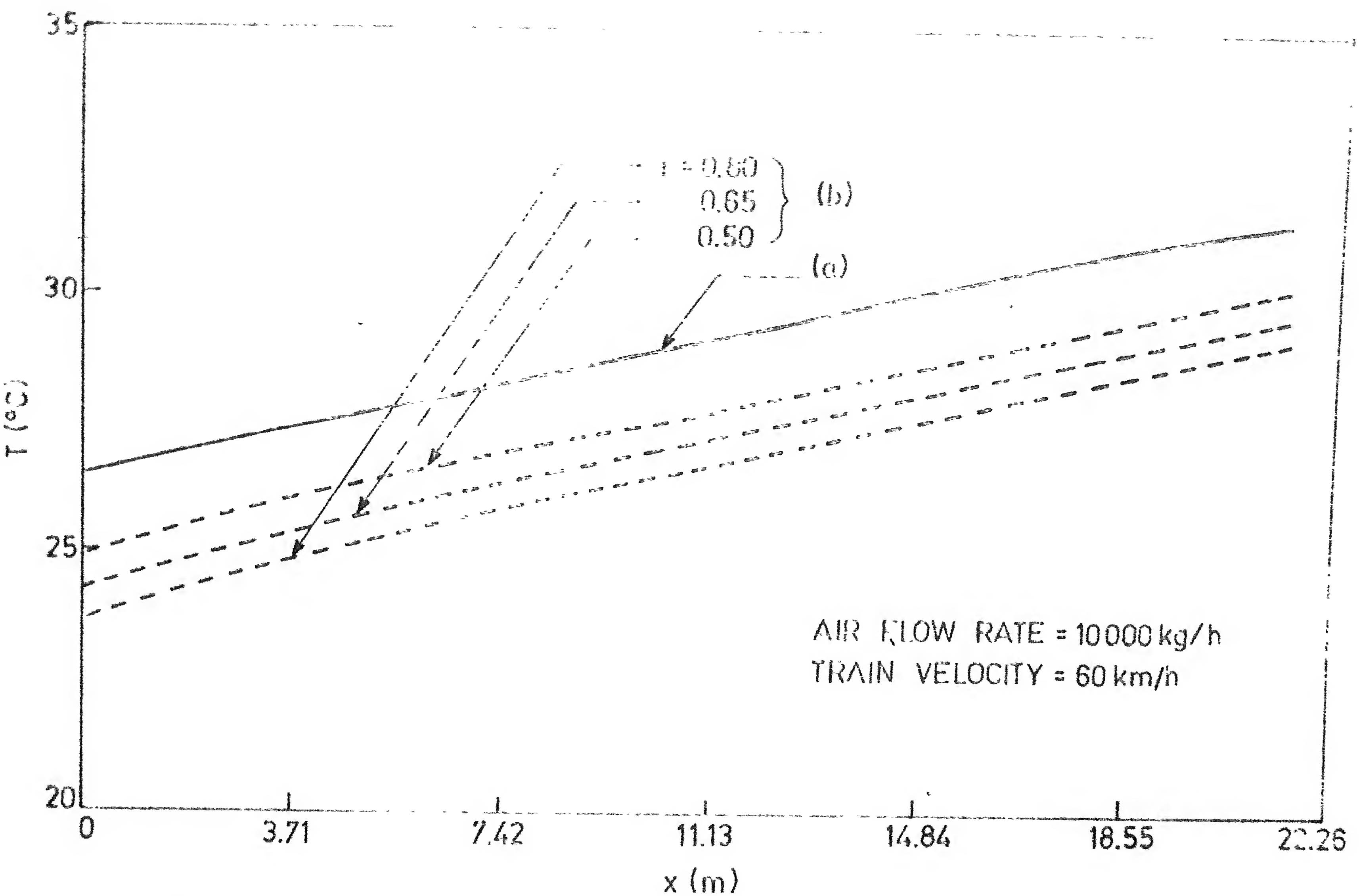

Fig. 4.11. Temperature distribution inside the coach for (a) without regeneration (b) with regeneration (Heatexchanger effectiveness (ε) = 0.60) (Place - Kanpur).

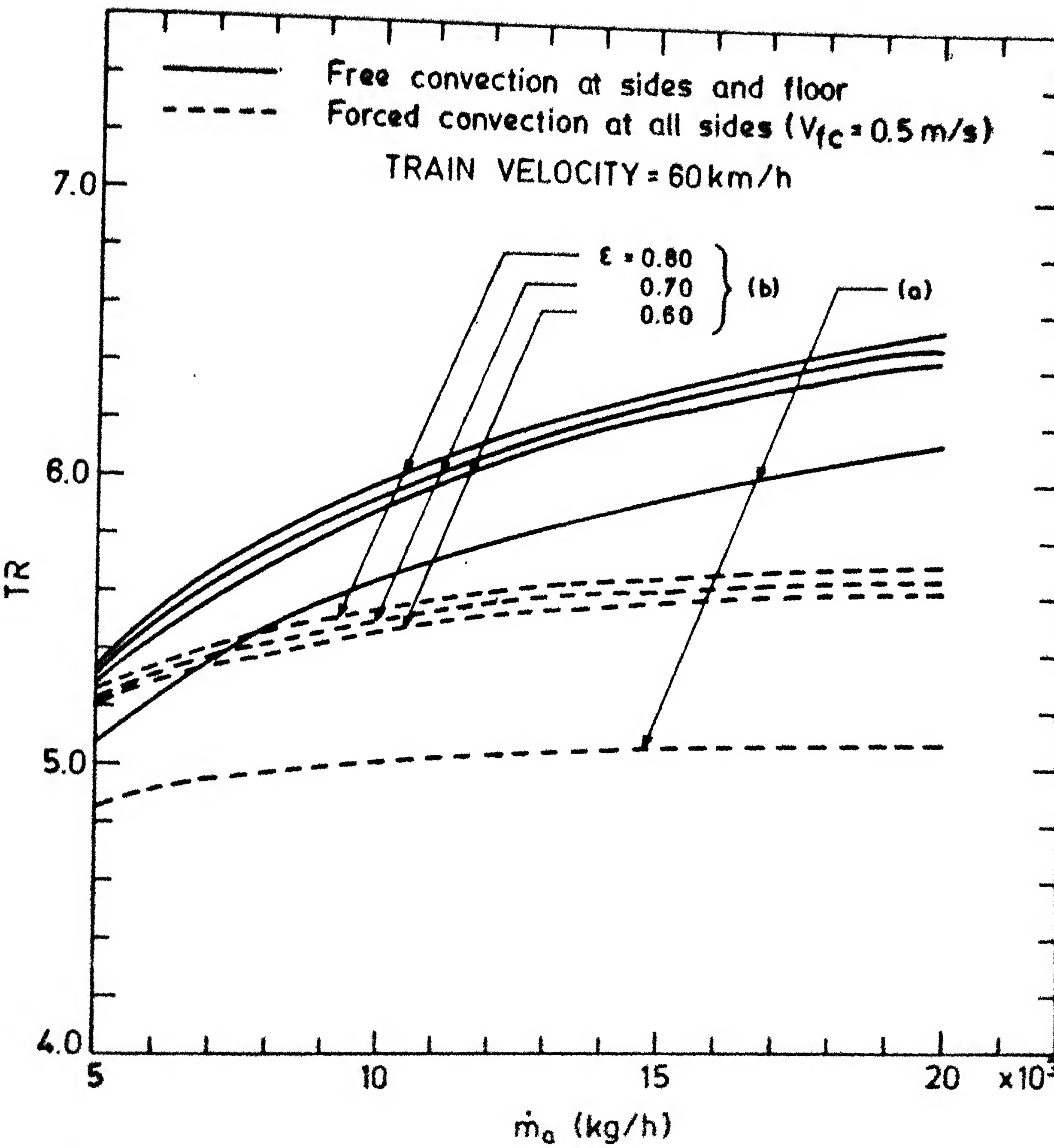

Fig. 4.12. Variation in tonnage with air flow rate for (a) without regeneration and (b) with regeneration using 50% re-circulation of exit air from the coach (Place - Kanpur).

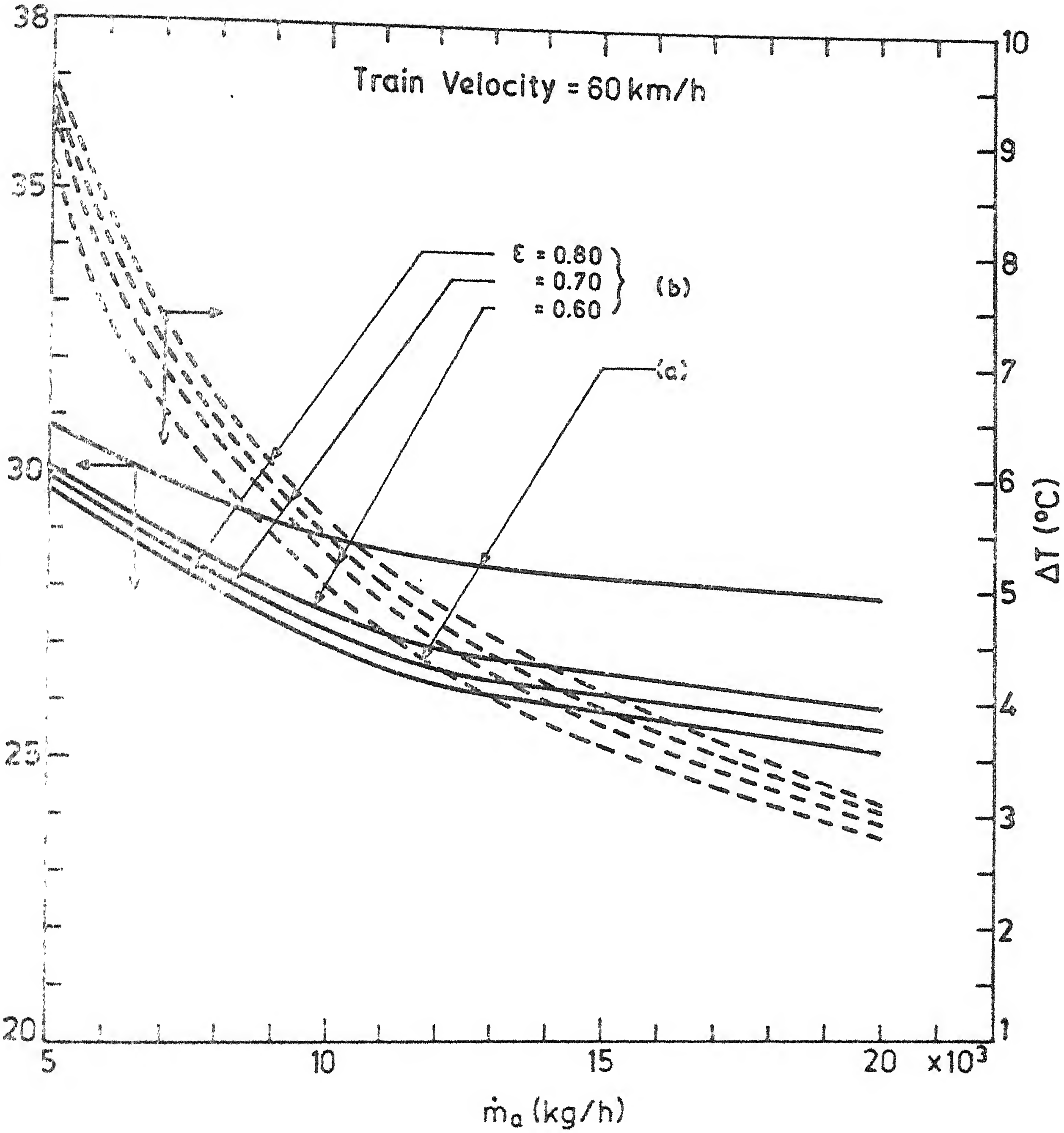

Fig 4.13 Variation in T_{av} and ΔT with air flow rate for (a) without regeneration and (b) with regeneration using 50% recirculation of exit air from the coach (Agra-Kanpur).

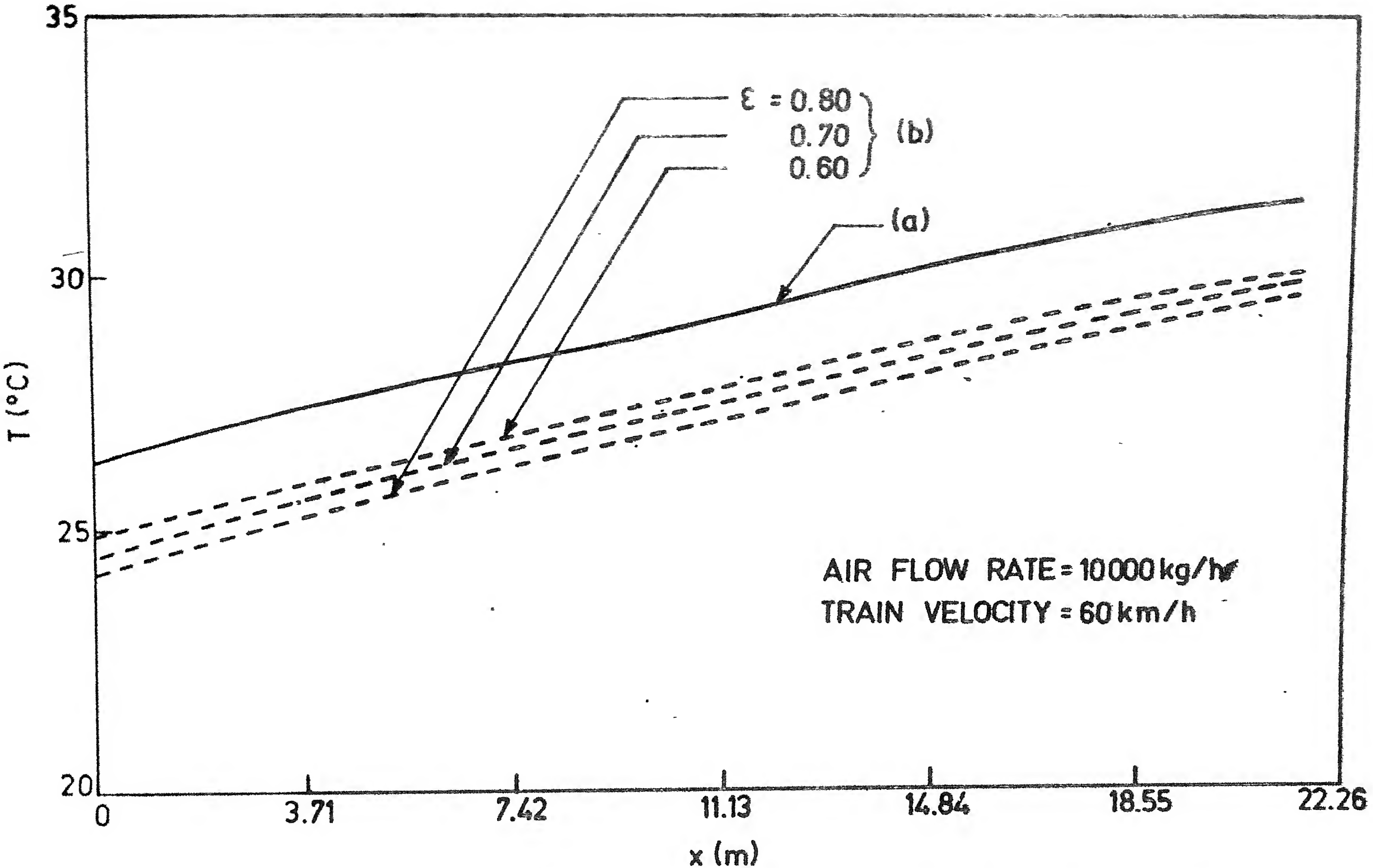

Fig. 4.14. Temperature distribution inside the coach for (a) without regeneration and (b) with regeneration using 50% recirculation of exit air from the coach (Place - Kanpur).

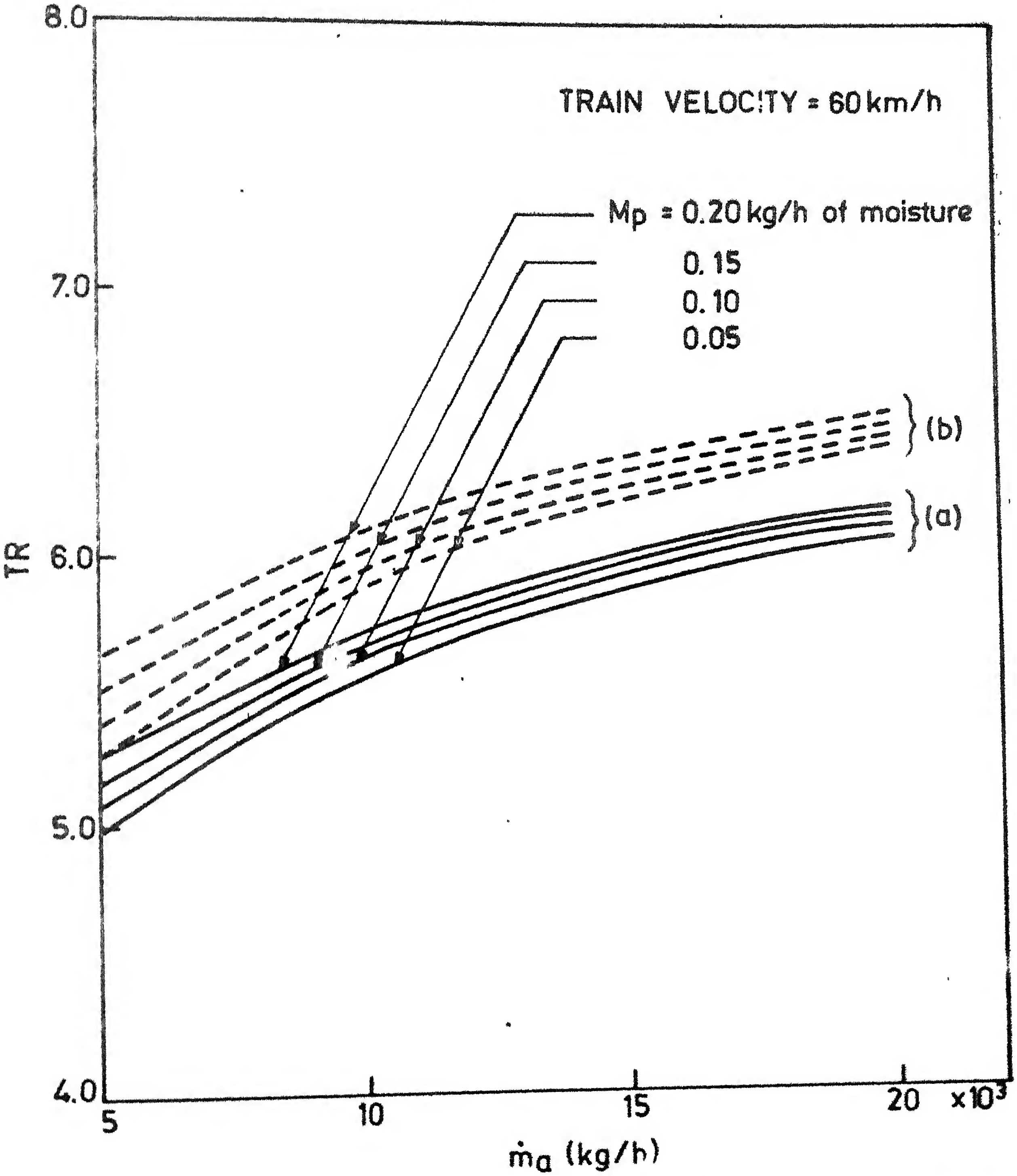

Fig. 4.15. Variation in TR with air flow rate for various occupant moisture release for (a) without regeneration and (b) with regeneration ($\varepsilon = 0.60$, $r = 0.50$) (Place - Kanpur).

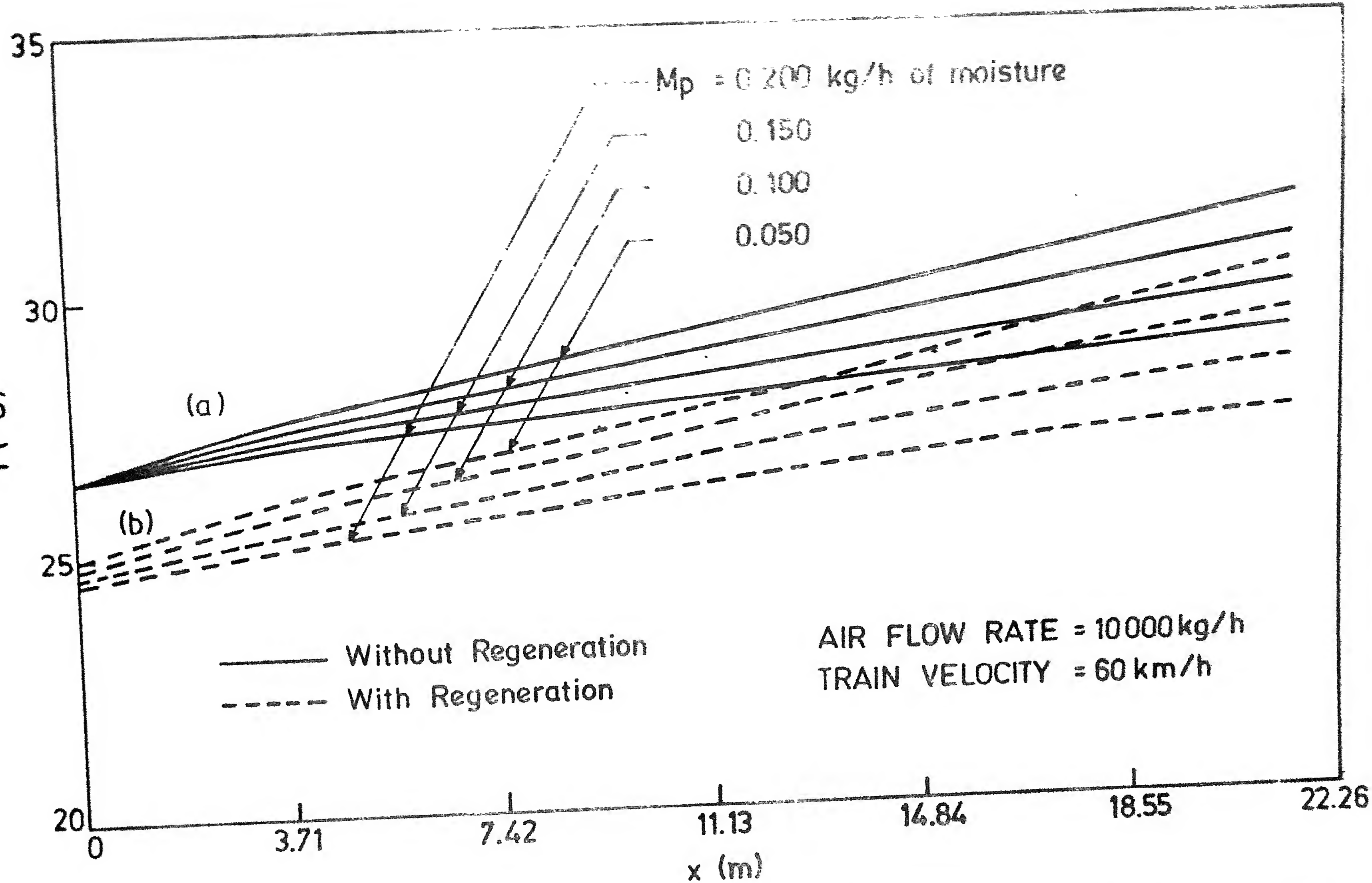

Fig. 4.16. Temperature distribution inside coach for various occupant moisture release for (a) without regeneration and (b) with regeneration ($\varepsilon = 0.60$, $r = 0.50$) (Place-Kanpur).

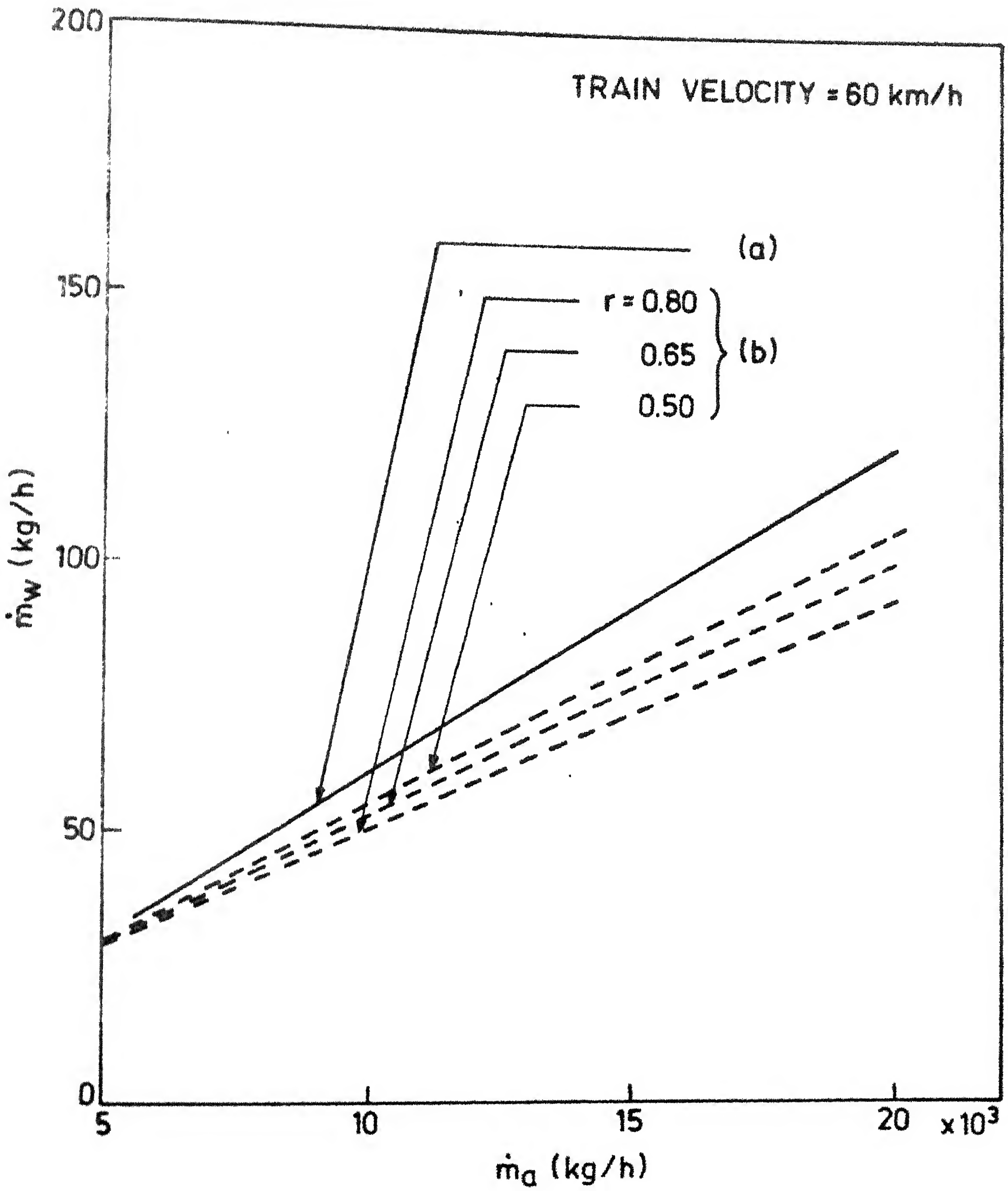

Fig 4.17. Variation in $\dot{m}_w$ with air flow rate for (a) without regeneration and (b) with regeneration (Heat-exchanger effectiveness = 0.60) (Place - Kanpur)

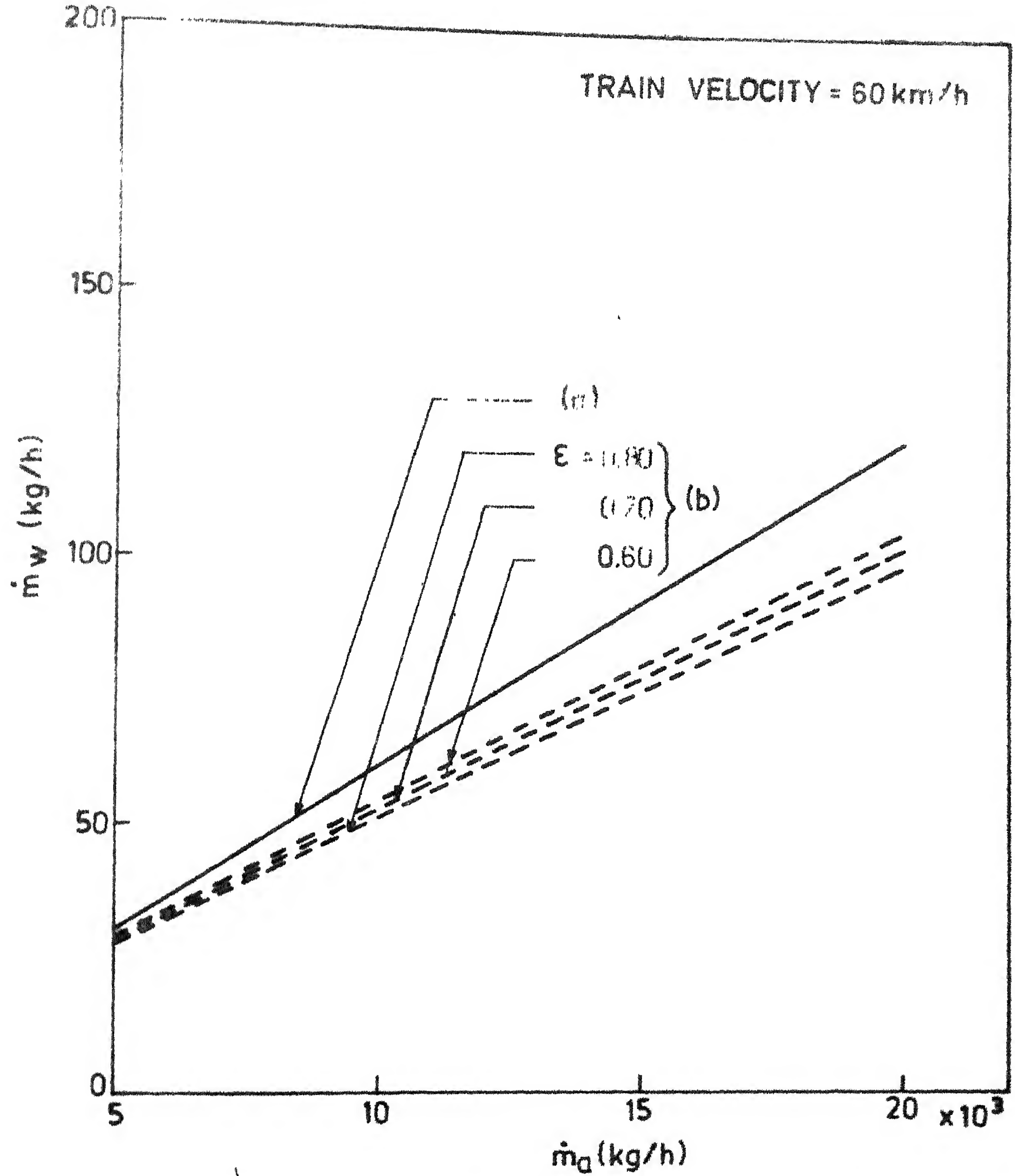

Fig. 4.18. Variation in $\dot{m}_w$ with air flow rate for (a) without regeneration and (b) with regeneration using 50% recirculation of exit air from the coach (Place - Kanpur)

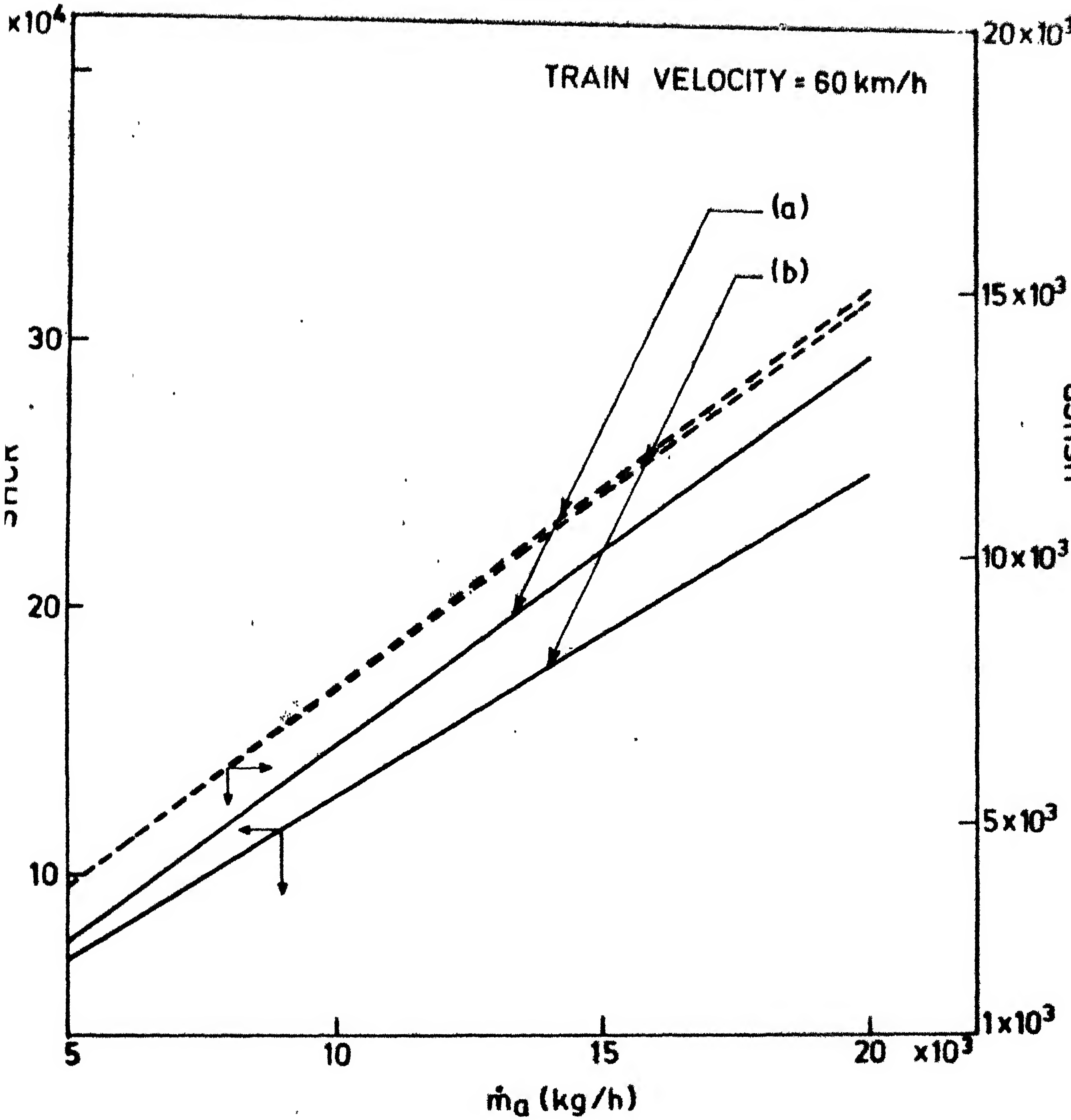

Fig. 4.19. Variation in SHCR and USHCR with air flow rate for (a) without regeneration (b) with regeneration (ϵ = 0.60, r = 0.50) (PLACE - KANPUR).

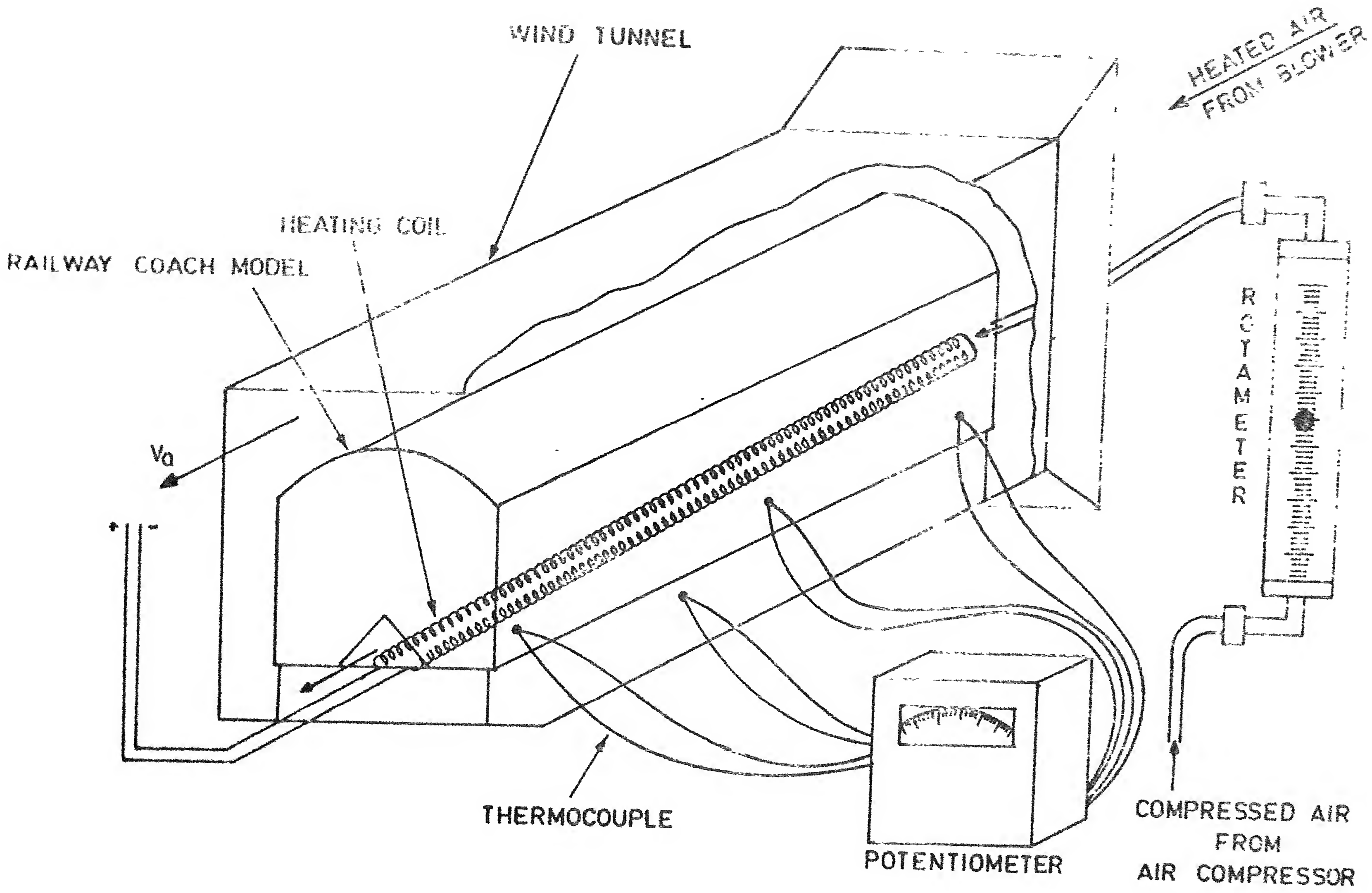

Fig. 4.20. Experimental set-up.

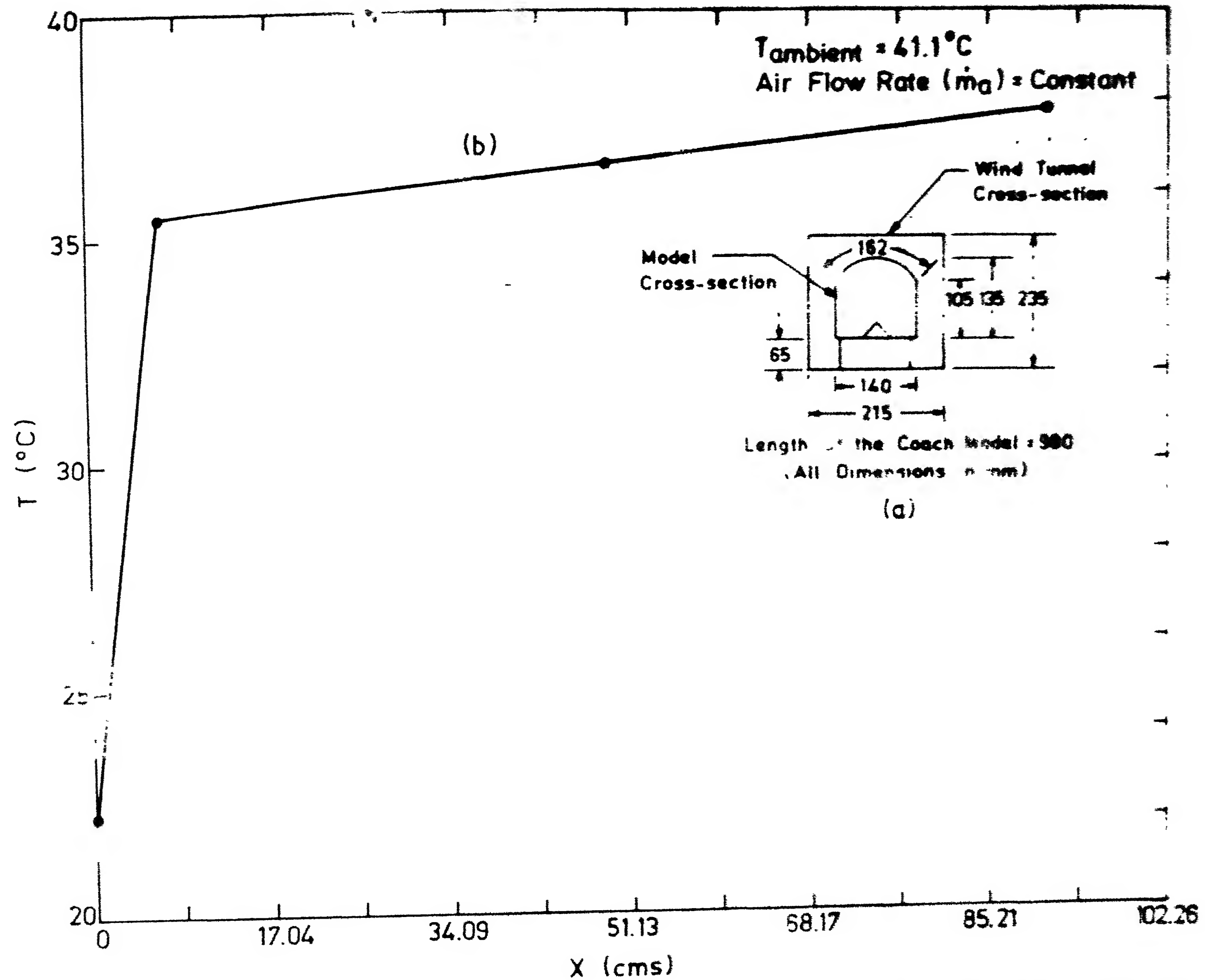

Fig. 4.21 (a) Dimensions of the experimental coach model and (b) Temp distribution inside the model.

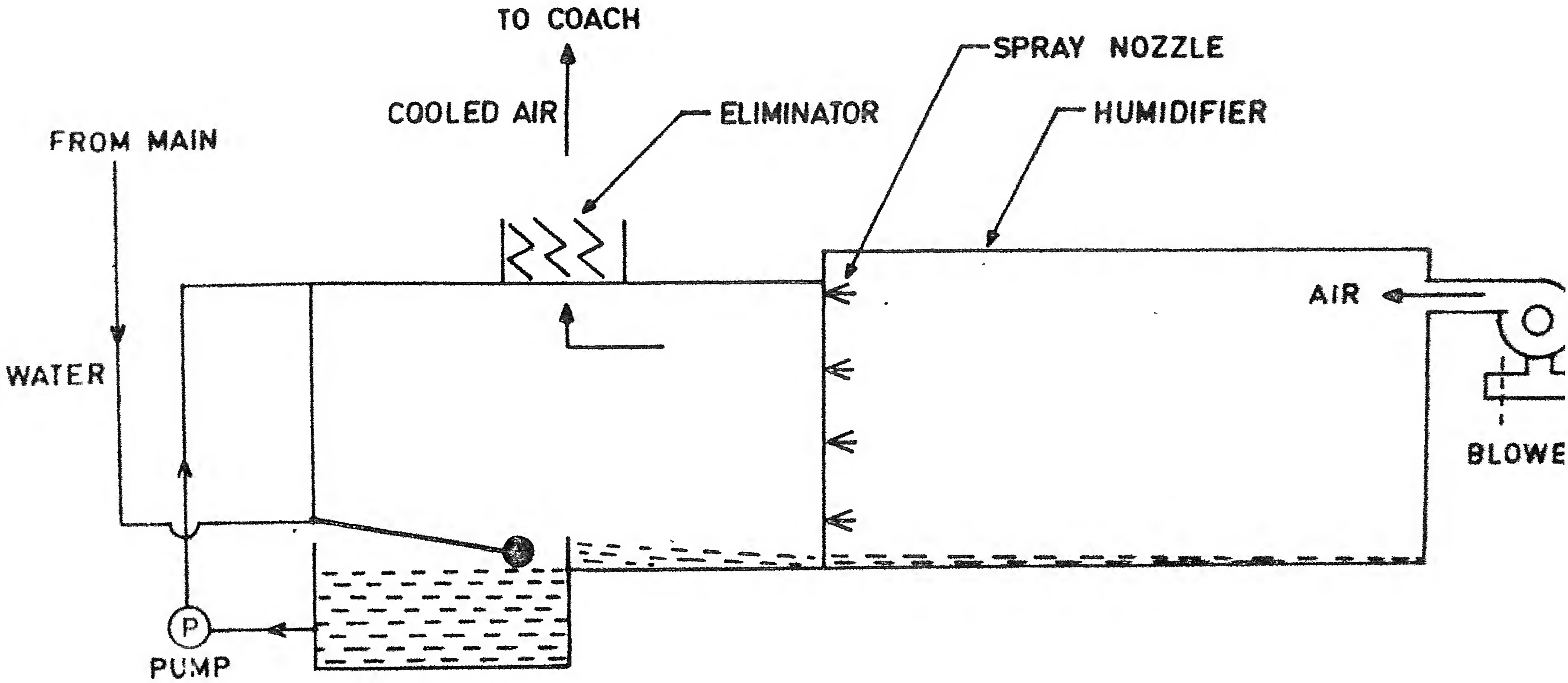

Fig. 4.22. Schematic representation of proposed evaporative cooling system for railway coach.

CHAPTER 5

5.1 CONCLUSIONS:

From the present study the following conclusions are arrived at :

1. The computer program has been developed to calculate cooling load, temperature distribution inside an evaporatively -cooled railway coach and for non-regenerative and regenerative evaporative cooling systems.
2. The results have been obtained for a wide range of operating variables. for three different train routes (SE, S and SW) .
3. The cooling load TR decreases by 1 to 3% with an increase in train velocity from 60 to 120 km/h.
4. Higher air flow rates give better comfort conditions within the coach. But the space requirement for the humidifier would be large in addition to bigger size of the blower and other components. Hence, an air flow rate in the range of 10,000 to 15,000 kg/h is recommended in view of the availability of space for the same underneath the coach.
5. The regenerative evaporative cooling system is advantageous compared to non-regenerative evaporative cooling system in terms of achievement of better inside conditions and less water consumption. For a six hourly service of the system per day, the

regenerative evaporative cooling system requires only 305 litres of water compared to non-regenerative system where the requirement is 370 litres of water.

6. The performance of the regenerative cooling system can be enhanced by either increasing the recirculation rate of exit air on the heat-exchanger effectiveness or both. However, it is found that the former is more effective than the latter, because the temperature inside the coach decreases by about 4.7% in the former as compared to only 3% in the latter.
7. The computed dimensions of the humidifier can easily be accommodated underneath the coach, thus making evaporative cooling practically feasible for a prototype railway coach.
8. The tonnage of the evaporative cooling system comes out to be in the range of 4-5 tons which is only half of that of the conventional 10 ton mechanically refrigerated air conditioning system used for railway coaches.

5.2 SCOPE FOR FURURE WORK

There is considerable scope for the extension of the present work. They are:

1. Analysis of heat and mass transfer for cooling load calculations of the coach can be carried out when the air is introduced through grilles from both ends of the coach.

2. The effect of activity of occupants inside the coach on the cooling load can be studied.
3. The cooling load may be calculated using combined free and forced convection for inside heat transfer coefficient.
4. The sizes of the humidifier, regenerative heat exchanger, supply duct, blowers and pumps can be optimised on the basis of overall cost and energy requirement.
5. An experimental investigation can be undertaken for a prototype railway coach.

REFERENCES

1. "American Society of Heating Refrigerating and Airconditioning Engineers' Hand book book of Fundamentals", Chap. 33, Air Washers Evaporative Air-cooling Equipment and Humidifiers, 1965 and 1966.
2. Watt, J.R, Evaporative Air Conditioning, The Industrial Press, New York, 1963, p.4
3. Singh, S.P., Effect of various Parameters on the Performance of a Desert Cooler, M.Tech Thesis, Deptt. of Mech.Engg. I.I.T.Kanpur, India, Dec. 1975.
4. Ravichandran, N., Design and Optimisation of a Desert Cooler, M.Tech Thesis, Dept. of Mech.Engg., I.I.T. Kanpur, India, Aug. 1974.
5. Srivastava, S.K., An Experimental Investigation into the Performance of a Desert Cooer, M.Tech Thesis, Deptt. of Mech. Engg., I.I.T.Kanpur, India Nov. 1980.
6. Same as [2], pp. 7-9.
7. Personal Communication with RDSO, Lucknow.
8. Same as [2], p.204.
9. Personal Communication with RDSO, Lucknow.
10. Murthy, S.N., and Prasad, M, Use of Direct Evaporative Cooling for Aircooling in Railway Coaches, Proceedings of the 13th National Conference on Fluid Mechanics and Fluid Power, R.E.C. Tiruchirapalli, Dec. 12-14, 1984, pp. 539-542.

11. Mani, A., Handbook of Solar Radiation for India, pp. 10-15

12. American Society of Heating Refrigerating and Airconditioning Engineers' Handbook of Fundamentals, 1981, p. 273.

13. Same as [12], p. 272.

14. Same as [12], pp. 27-37.

15. Chapman, A.J., Heat Transfer, The Macmillan Co., New York, 1967, p. 330.

16. Drawing Supplied by RDSO, Lucknow

17. Same as [1], pp. 422-424.

18. Same as [15], p. 331.

19. Threlkeld, J.L., Thermal Environmental Engineering, Prentice Hall, INC, 1970, pp. 323-326.

20. Same as [22], p. 338

21. Same as [22], p. 340.

22. Kadambi, V., and Hutchinson, F.W., Refrigeration, Air Conditioning and Environmental Control in India, Prentice Hall of India Pvt.Ltd., 1968, pp. 14-21.

23. Indian Standards Institutions Tables 1st edn, 1976, p. 9.

24. Same as [5], pp. 20-21.

25. Pierce, B.O, and Foster Ronald, M., A Short Table on Integrals, Oxford and IBH Publishing Co.,1966, p.72

APPENDIX A

EVALUATION OF COACH PARAMETERS

A.1 EVALUATION OF COACH PERIMETER (P_c)

We have the dimensions of the coach as $L_1 = 21.337$ m, $L_w = 3.061$ m, $L_h = 2.075$ m.

$$P_c = P_1 + P_2 = P_1 + (2 L_h + L_w) \tag{A 1}$$

where P_1 = perimeter of the curved ceiling of the coach (m)

P_2 = perimeter of the other three sides of the coach (m).

To calculate P_1 we consider the ceiling as approximately elliptical with major axis as 'a' and minor axis as 'b'. Then equation of the ellipse is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{A 2}$$

Putting $x = a \sin \theta$, $y = b \cos \theta$

$$dx = a \cos \theta, \quad dy = - b \sin \theta \tag{A 3}$$

$$\therefore \quad P_1 = \int \sqrt{(dx)^2 + (dy)^2}$$

$$= \int_0^{\pi} \sqrt{a^2 \cos^2\theta + b^2 \sin^2\theta}\, d\theta = a \int_0^{\pi} \sqrt{1 - (1-b^2/a^2) \sin^2\theta}\, d\theta \tag{A 4}$$

Putting $k^2 = 1-b^2/a^2$, in Eq. (A 4) one gets:

$$P_1 = a \int_0^{\pi} \sqrt{(1 - k^2 \sin^2\theta)}\, d\theta \tag{A 5}$$

using the following Eq. (A 6) from [25]:

$$\int_0^{\Phi} \sqrt{1 - k^2\sin^2\theta}\, d\theta = (2/\pi)\, \Phi . E + \sin \Phi \cos \Phi \left[1\tfrac{1}{2} \cdot \tfrac{1}{2} k^2 + \frac{1}{2.4} k^4 A_4 + \frac{1.3}{2.4.6} k^6 A_6 + \ldots\right]$$

$$= E(\Phi, k)$$

where $E = \int_0^{\pi/2} \sqrt{1 - k^2 \sin^2\theta}\, d\theta = \frac{\pi}{2} \left[1 - \left(\frac{1}{2}\right)^2 k^2 - \left(\frac{1.3}{2.4}\right)^2 \frac{k^2}{3} - \left(\frac{1.3.5}{2.4.6}\right)^2 \frac{k^6}{5} - \ldots\ldots\right]$ if $k^2 < 1$

For $\Phi = \pi$ we have

$$\int_0^{\pi} \sqrt{1 - k^2 \sin^2\theta}\ .\ d\theta = 2E \quad \text{or } P_1 = 2aE \qquad (A\ 7)$$

(A. 2) Area of cross-section (A_c)

$$A_c = A_1 + A_2 \qquad (A\ 8)$$

A_1 = area of the semi-ellipse under the ceiling (m^2)

A_2 = area bounded by the walls and floor (m^2)

For semi-ellipse

$$A_1 = \pi\ ab/2 \qquad (m^2) \qquad (A\ 9)$$

and $A_2 \simeq L_h\ L_w \qquad (m^2) \qquad (A\ 10)$

The final results obtained are:

$P_c = 10.665$ m

$A_c = 7.533\ m^2$

APPENDIX B

EVALUATION OF T_{wb}' FOR REGENERATION

From: Eq. (2.83)

$$p_s\,(T_{wb}') = \frac{221.2}{e^M} \qquad \text{(B 1)}$$

where

$$M = [7.2137 + 1.1520 \times 10^{-5} - 4.787 \times 10^{-9}$$

$$(T_{wb}' + 273.16)\;(T_{wb}' - 210)^2]\;(\frac{647.31}{T_{wb}'+273.16} - 1] \qquad \text{(B 2)}$$

Also

$$(p_v') = p_s\,(T_{wb}') - \frac{[\,1.0132 - p_s(T_{wb}')][\,T_a - T_{wb}'\,]}{1547 - 1.44\,T_{wb}'} \qquad \text{(B 3)}$$

$$f(T_{wb}') = p_s(T_{wb}') - \frac{[1.0132 - p_s(T_{wb}')][\,T_a - T_{wb}'\,]}{1547 - 1.44\,(T_{wb}')} - \bar{p}_v' = 0$$

using Newton-Raphson method

$$(T_{wb}')_{k+1} = (T_{wb}')_k - \frac{f(T_{wb}')_k}{f'(T_{wb}')_k} \qquad \text{(B 4)}$$

with k = no. of iterations

where $f'(T_{wb}') =$

$$(1547 - 1.44\,T_{wb}')\;(T_a - T_{wb}')(221.2\,e^{-M}\,\frac{dM}{dT_{wb}'})/(1547 - 1.44(T_{wb}')^2)$$

$$-(1547 - 1.44\,T_{wb}')(1.0132 - 221.2\,e^{-M})/(1547 - 1.44(T_{wb}')^2)$$

$$+1.44\,(T_a - T_{wb}')(1.0132 - 221.2\,e^{-M})/(1547 - 1.44(T_{wb}')^2)$$

Putting $(T_{wb}')_1 = T_{db}$, the above iteration is performed k times.

APPENDIX C

EVALUATION OF REFLECTANCE OF GLASS

A subroutine for calculating the reflectance of glass (r_{cs}) has been incorporated in the main program which uses Lagranjian interpolation method for calculating the value of r_{cs} for $\theta_{cs} > 50^{\circ}$

$$f(x) \approx Ln(x) = \sum_{k=0}^{n} \frac{l_k(x)}{l_k(x_k)} f_k$$ where $x_o, \ldots x_n$ are

not necessarily equally spaced and

$$l_o(x) = (x-x_1)\ (x-x_2) \ldots\ldots\ldots (x-x_n)$$

$$l_k(x) = (x-x_o) \ldots\ldots\ldots (x-x_{k-1})\ (x-x_{k+1}) \ldots (x-x_n),\ k=1, \ldots n-1$$

$$l_n(x) = (x-x_o)\ (x-x_1) \ldots\ldots (x-x_{n-1})$$

The data used for interpolation taken from graph [3] is given as under:

TABLE B.1

VALUES OF REFLECTANCE FOR VARIOUS INCIDIENT ANGLES FOR GLASS

$\theta_{cs}(^{o})$	r_{cs}
50	0.06
60	0.09
70	0.165
80	0.38
90	1.00

For $\theta_{cs} < 50^{\circ}$ linear interpolation is used:

$$r_{cs} = 0.02 + (8 \times 10^{-4})\, \theta_{cs} \qquad \text{(C 1)}$$

The window glass is of double strength quality with the following values:

$$t_g = 3.175 \text{ mm}$$

$$K = 7.64 \times 10^{-3} \text{ mm}^{-1}.$$

APPENDIX D

COMPUTER PROGRAM

Refer computer program

```
C     PROGRAM FOR COOLING LOAD CALCULATIONS IN AN EVAP. COOLED PLYCOACH
C     WITHOUT RECIRCULATION OF EXIT AIR OF COACH
C     ******************************************************************
C     PLACE=11-KANPUR;21-CHANDIGARH;0-DELHI;;34-BARODA
C           22-BHOPAL;23-NAGPUR;24-HYDERABAD;12-ALLAHABAD;13-PATNA
C       14-JAMSHEDPUR ,31-JODHPUR;32-JAIPUR;33-AHMEDABAD
C     ROUTE=CODE FOR DIRECTIONS OF THE MOVING COACH
C           1   FOR N-SE OR N-NW
C           2   FOR N-S OR N-S
C           3   FOR NE-SW  OR SW-NE
C     MONTH=5 FOR MAY
C          =7 FOR AUG
C     IT=1 BEFORE  SOLAR NOON
C         =2 AFTER SOLAR NOON
C     =3 AT SOLAR NOON
C     SIDE=1 FOR EAST FACING SIDE OF COACH
C         =2 FOR WEST FACING SIDE OF COACH
C     ANGLES:LAT-LATITUDE ANGLE,DEC-DECLINATION ANGLE,HOUR-HOUR ANGLE
C     SIGH-SURFACE AZIMUTH ANGLE MEASURED FROM SOUTH(ASHRAE 1981)
C     TILT-INCL.ANGLE OF SURFACE MEASURED UPWARD FROM HORIZONTAL
C     PHI-SOLAR AZIMUTH ANGLE MEASURED FROM SOUTH
C     GAM-SURFACE-SOLAR AZIMUTH ANGLE;BETA-ALTITUDE ANGLE
C     THETA-INCIDENCE ANGLE
C     LEN=LENGTH OF THE COACH;LW=WIDTH;LH=HEIGHT
C     ******************************************************************
      REAL LEN,LH,LW,IDN,IDIR(3,2),IDIF(3,2),IREF(3,2),ITOTAL(2,2),
     1LAT,LDASH,KGLASS,INDEX,IST,ISTH,ISTM,NOON,LAPPTM,LMT,LENAW,MRT,
     1ICL,METAB,HC
      INTEGER PLACE,MONTH,DIRN,SIDE,SIDER,COMP,COMPR,DAY,V,VR,QTCOND(2
     15),QTSOLA(25),QTOTAL(25),QTRELE(25),ROUTE,VELOC,TIME,CASE,PART
     1,QTSTRU(25)
C     ****************************************************************
      DIMENSION X(25),T(25),TMEAN(25),Y(4),EXPON(4),ALP(2),COEF(4),
     1SIGH(2),RTHETA(4,2),THGLAS(4,2),TRANS(4,2),RADTEM(25),TWALL(25,
     14),ALPHA(4,2),REFTOT(4,2),TOT(4,2),AMC(25,4),RC(25,4),QCOND(25),
     1QRELEA(25),WRELEA(25),QSOLAR(25),W(25),DT(25,4),YRW(3),FOCO(3),
     1WTRELE(25),REC(25,4),ROP(25,4),DTEM(25,4,2),XMEAN(25),MIX(25
     1,4,2),HOX(25),RESIST(4),U(25,4,2),TSOL(25,4,2),TRANGL(4,2),
     1REST(25,4,2),FLOMAS(5),MA(5),IFLOW(5),FLOW(5),FOCONV(5),
     1TOWALL(25,3,2),TIWALL(25,3,2),QSTRUC(25),WMEAN(25),H(25),
     1TEM(25,50),TAVG(25,50)
C     ******************************************************************
      OPEN(UNIT=30,DEVICE='DSK',FILE='MANI.FOR')
      OPEN(UNIT=31,DEVICE='DSK',FILE='DATA.FOR')
      OPEN(UNIT=32,DEVICE='DSK',FILE='TIME.DAT')
      OPEN(UNIT=40,DEVICE='DSK',FILE='ANGLE.DAT')
      OPEN(UNIT=41,DEVICE='DSK',FILE='INTENS.DAT')
      OPEN(UNIT=42,DEVICE='DSK',FILE='FOR42.DAT')
      OPEN(UNIT=45,DEVICE='DSK',FILE='TON.DAT')
      OPEN(UNIT=46,DEVICE='DSK',FILE='COMP.DAT')
      OPEN(UNIT=47,DEVICE='DSK',FILE='WASH.DAT')
      OPEN(UNIT=48,DEVICE='DSK',FILE='DUCT.DAT')
C     IST=INDIAN STANDARD TIME;LOCAL APPARENT TIME=LOCAL SOLAR TIME
C     ****************************************************************
      READ(31,*),(FLOMAS(M),M=1,4)
      VELOC=150
      DAY=21
      DIRN=1
      MONTH=5
      IST=12.00
      FOCONV(1)=0.50;FOCONV(2)=0.75;FOCONV(3)=1.00
C     ****************************************************************
      WRITE(41,10)
      WRITE(45,10)
      WRITE(46,10)
      WRITE(47,10)
      WRITE(48,10)
      WRITE(41,60)
      WRITE(45,60)
      WRITE(46,60)
      WRITE(47,60)
      WRITE(48,60)
      WRITE(41,100),DAY,MONTH,IST,VELOC,DIRN
      WRITE(45,100),DAY,MONTH,IST,VELOC,DIRN
      WRITE(46,100),DAY,MONTH,IST,VELOC,DIRN
      WRITE(47,100),DAY,MONTH,IST,VELOC,DIRN
      WRITE(48,100),DAY,MONTH,IST,VELOC,DIRN
      WRITE(45,101)
      WRITE(46,102)
      WRITE(47,103)
      WRITE(48,104)
      WRITE(45,810)
      WRITE(46,811)
      WRITE(47,812)
      WRITE(48,813)
C     ***********************************************************
      DO 812 NOOF=1,1
      READ(30,*),ROUTE,PLACE,LAT,TDB,TWB,SIGH(1),SIGH(2),DEGCON,MINCON
```

```
C     *************************************************************
      WRITE(41,155),ROUTE
      WRITE(45,207),ROUTE
      WRITE(46,207),ROUTE
      WRITE(47,207),ROUTE
      WRITE(48,207),ROUTE
      DO 1000 CASE=1,2
      DO 2000 PART=1,3
C     ****************************************************************
C     O U T P U T   F O R M A T   S T A T E M E N T S
60    FORMAT(5X,'N O   R E G E N E R A T I O N'/5X,25('*')/)
      IF(CASE .EQ. 1) GO TO 1050
      GO TO 4
1050  GO TO(1,2,3),PART
   1  WRITE(45,70)
      WRITE(46,70)
      WRITE(47,70)
      WRITE(48,70)
      WRITE(41,70)
      GO TO 1222
70    FORMAT(5X,'CASE-I-A FREE CONVECTION ONCE AT SIDES AND FLOOR'/
     15X,40('*')/)
2     WRITE(45,80)
      WRITE(41,80)
      WRITE(46,80)
      WRITE(47,80)
      WRITE(48,80)
      GO TO 1222
80    FORMAT(5X,'CASE-I-B FREE CONVECTION TWICE AT SIDES AND FLOOR'/
     15X,40('*')/)
3     WRITE(45,90)
      WRITE(41,90)
      WRITE(46,90)
      WRITE(47,90)
      WRITE(48,90)
      GO TO 1222
90    FORMAT(5X,'CASE-I-C FREE CONVECTION THRICE AT SIDES AND FLOOR'/
     15X,40('*')/)
4     WRITE(45,125),FOCONV(PART)
      WRITE(46,125),FOCONV(PART)
      WRITE(41,125),FOCONV(PART)
      WRITE(47,125),FOCONV(PART)
      WRITE(48,125),FOCONV(PART)
125   FORMAT(5X,'CASE-II FORCED CONVECTION AT ALL SIDES OF COACH WITH
     1 VELOCITY(M/S)= ',F4.2/5X,70('*')/)
100   FORMAT(40X,'DAY=',I2,2X,'MONTH=',I2,2X,'IST=',F5.2/35X,42('*')//
     145X,'VELOCITY OF COACH(KMS/H)=',I3,1X,'DIRN=',I2,1X,'VELOCITY
     1 AND SUPPLY AIR IN          SAME DIRECTION'/45X,50('*')//)
101   FORMAT(25X,'COOLING LOADS AND TEMPERATURE RISE'/25X,45('*')/)
102   FORMAT(25X,'COACH CONDITIONS FOR THERMAL COMFORT'/25X,50('*')/)
103   FORMAT(25X,'AIR WASHER DIMENSIONS'/25X,25('*')/)
104   FORMAT(25X,'DUCT DIMENSIONS AND BLOWER POWER'/25X,55('*')/)
810   FORMAT(10X,80('=')/
     12X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'MA(KG/H)',2X,'EFF',
     13X,'TINL',3X,'TEXIT',2X,'AVGTEM',3X,'DELT',3X,'QSTRUCT',
     1X,'QR',3X,'LOAD',2X,'TON',3X,'TONEF',2X,'MW(KG/H)',
     12X,'P(HP)',2X,'QTON'/2X,100('=')/)
811   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'WA',3X,'RHTDB',2X,'
     1MA(KG/H)',2X,'TINL',2X,'WINL',2X,'RHINL',3X,'TEXIT',2X,'WEXIT',
     12X,'RHEXIT',3X,'MW(KG/H)',2X,'MRT(C)',2X,'COMFV',2X,'HIN',2X,
     1'HEX',2X,'QTON',2X,'TON',
     1/2X,100('*'))
812   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'MA(KG/H)',2X,'SPVOL'
     1,2X,'EFF',2X,'Q(CUM/H)',2X,'FACEV(M/H)',3X,'L(M)',3X,'A(SQM)',2
     1X,'V(CUM)'2X,'MW(KG/H)'/2X,100('*'))
813   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'MA(KG/H)',3X,'VDUCT
     1(M/S)',3X,'Q(CUM/H)',3X,'PDROP(MM)',3X,'DIA(M)',2X,'H(M)',3X,
     1'W(M)',2X,'P(HP)'/2X,100('*'))
155   FORMAT(10X,10('=')/10X,'J=2',2X,'SIDE=1',2X,'M=1',2X,'ROUTE=',I3
     1        /10X,10('=')/2X,'PLACE',
     13X,'TDB',3X,'ITOTAL',3X,'I',3X,'XMEAN',3X,'TMEAN',3X
     1,'TSOL',5X,'TWO',5X,'TWI',5X,'HOX',5X,'HIX',5X,'RESIST',5X,'Q',
     12X,'HEAT1',2X,'HEAT2',2X,'HEAT3'/5X,95('*'))
C     *************************************************************
1222  CONTINUE
      ISTH=12.0
      ISTM=0.0
      DEGSM=82.0
      MINSM=15.0
      SMMIN=DEGSM*60.0+MINSM
      MERMIN=DEGLON*60.0+MINLON
      DIFLON=MERMIN-SMMIN
      COCTN1=(DIFLON/60.0)*4.0
      LMT=ISTH*60.0+ISTM+COCTN1
      EQTIME=3.0+37.0/60.0
      NOON=12.0*60.0
      LAPPTM=LMT+EQTIME
      IF=DIM(LAPPTM,NOON)
```

```
C     ************************************************************
10    FORMAT(5X,80('*')/10X,'CODES:  ROUTE(1-N-SE)-DELHI-(0),KANPUR-
     1(11),ALLAHABAD-(12),PATNA-(13),JAMSHEDPUR-(14)'/19X,'ROUTE(2-N-
     1-S)-CHANDIGARH-(21),DELHI-(0),BHOPAL-(22),NAGPUR-(23),HYDERABAD
     1-(24)'/19X,'ROUTE(3-N-SW)-DELHI(0),JODHPUR-(31),JAIPUR-(32),AHM
     1EDABAD-(33),BARODA-(33)'/5X,80('*'))
C     ************************************************************A532
      VEL=VELOC*1000.0
      DEC=20.0
      A=1103.0
      B=0.196
      C=0.121
      EFF=0.75
      PI=3.1415926
      RLAT=LAT*PI/180.0
      RDEC=DEC*PI/180.0
      RHOUR=HOUR*PI/180.0
      RBETA=ASIN(COS(RLAT)*COS(RHOUR)*COS(RDEC)+SIN(RLAT)*SIN(RDEC))
      BETA=RBETA*180.0/PI
      TINL=TDB*(1.0-EFF)+TWB*EFF
      WA=0.622*PV(TDB,TWB)/(1.0132-PV(TDB,TWB))
      WINL=0.622*PV(TINL,TWB)/(1.0132-PV(TINL,TWB))
      RHTDB=PV(TDB,TWB)/PS(TDB)
      RHINL=PV(TINL,TWB)/PS(TINL)
      T(1)=TINL
      W(1)=WINL
      IF(II .EQ. 3) GO TO 1445
      RPHI=ACOS((SIN(RBETA)*SIN(RLAT)-SIN(RDEC))/(COS(RBETA)*COS(RLAT)
     1))
      PHI=RPHI*180.0/PI
      GO TO 2210
1445  PHI=0.0
2210  SINBET=SIN(RBETA)
      IDN=(A/EXP(B/SINBET))*3.6
      CPA=1.004
C     ************************************************************
C     VALUES OF VA IOUS COACH PA RAMETE RS A RE GIVEN BELOW
C     GEN.FORM OF HI=COEF*(DTEM)**EXPON;DTEM=TWI-T;T=TEMP INSIDE COACH
C     COACH DIVIDED INTO 23 SECTIONS;NOOF PERSONS=76;NOOF WINDOWS ON
C     ONE SIDE=23,SENS.HT.RELEASE=470KJ/HR/PERSON;LATNT=80 GMS WATER/H
C     R/PERSON;AREA=AREA OF X-SECTION;PERIM=PERIMETER OF X-SECTION
C     CLOTHING OF PERSONS-TROPICAL LIGHT SUMMER CLOTHING
      LEN=21.337
      LH=3.061
      BH=2.075
      PERSON=76.0
      WINDOW=23.0
      AREA=7.533
      PERIM=10.565
      VOL=AREA*LEN
      METAB=470.0
      FCL=1.1
      ICL=0.50
      ADASH=[illegible].427
      ADU=1.[illegible]6
      REFF=0.0
      OTRIPL=METAB*PERSON/VOL
      WTRIPL=0.065*PERSON/VOL
      AREWIN=0.61*0.60
      SOAREA=(WINDOW/LEN)*AREWIN
      COAREA=(LEN*LH-WINDOW*AREWIN)/LEN
C     X=DISTANCE FROM POINT OF SUPPLY OF HUMIDIFIED AIR
      X(1)=0;X(24)=21.337
C     J=CODE FOR STUCTURE;J=1 FOR SIDE WALL;J=2 FOR CEILING
C     =3 FOR GLASS WINDOW;J=4 FOR FLOOR
      COEF(1)=4.74;COEF(4)=5.47;COEF(3)=5.80
      EXPON(1)=0.33;EXPON(4)=0.33;EXPON(3)=0.25
      Y(1)=1.33;Y(4)=1.33;Y(3)=1.25
      ALP(1)=0.50;ALP(2)=0.40
      RHOG=0.20
C     VALUES OF STRUCTURE RESISTANCES GIVEN BELOW
C     COMMON WINDOW GLASS (QUALITY-DOUBLE STRENGTH) USED FOR COACH
C            THICKNESS OF ABOVE GLASS=0.125 INCH=3.0MM
C     CONDUCTIVITY OF GLASS=2.49 KJ/HR-M-C=0.4 BTU/HR-FT-F
      TGLASS=0.125*25.4*1.0E-3
      KGLASS=2.49
      RESIST(1)=0.0562;RESIST(2)=0.0704;RESIST(4)=0.1139
      RESIST(3)=TGLASS/KGLASS
C     FLOMAS=MASS FLOW RATE OF AIR IN KG/HR
C     M=1,FLOMAS=10000/M=2-15000,M=3-20000,M=4-25000,M=5-30000KG/HR
C     VEL =RELATIVE VEL OCITY OF MOVING COACH CONSIDERING WIND SPEED
C     V=1,VEL(V)=30000M/HR;V=2-60000M/HR;V=3-90000M/HR;V=4-120000M/HR
C     ************************************************************
      DO 88 M=1,4,3
C     ************************************************************
      DO 159 I=1,23
      IP=I
      [illegible]
```

```
C     CALCULATION OF HOX FOR TURBULENT FLOW AT VARIOUS XMEAN
      X(I+1)=X(I)+LEN/23.0
      XMEAN(I)=(X(I)+X(I+1))/2.0
         HOX(I)=0.0243*(VEL**0.8)*(XMEAN(I)**(-0.2))
      DO 1220 N=1,20
      NR=N
      TEM(I,1)=T(I)
      DO 450 J=1,4
      DO 550 SIDE=1,2
      JR=J
      SIDER=SIDE
      IF(J .EQ. 4) GO TO 505
      RTILT=AT(JR,SIDER)
      TILT=RTILT*(180.0/PI)
      IF(J .EQ. 2) GO TO 677
      GAM=AG(SIDER,IT,SIGH,PHI,LAT,DEC)
      RGAM=GAM*(PI/180.0)
      RTHETA(J,SIDE)=ACOS(COS(RBETA)*COS(RGAM))
      GO TO 224
677   RTHETA(J,SIDE)=ACOS(SIN(RBETA))
224   IDIR(J,SIDE)=IDN*COS(RTHETA(J,SIDE))
      CONTINUE
      THETA=RTHETA(J,SIDE)*(180.0/PI)
C     ****************************************************************
      IF(J .EQ. 2 ) GO TO 221
      IF(GAM .GT. 90.0) GO TO 55
      IDIR(J,SIDE)=IDN*COS(RTHETA(J,SIDE))
      GO TO 56
55    IDIR(J,SIDE)=0
221   CONTINUE
56    IDIF(J,SIDE)=IDN*C*FSS(JR,SIDER,RTHETA)
      IREF(J,SIDE)=IDN*RHOG*FSG(JR,SIDER)*(C+SINBET)
C     ****************************************************************
      IF(J .EQ. 1 .OR. J .EQ. 2) GO TO 500
      THGLAS(1,SIDE)=RTHETA(3,SIDE)*180.0/PI
      THGLAS(2,SIDE)=50.0
      THGLAS(3,SIDE)=50.0
      COEXT=0.194
      THICK=0.125
      DO 550 COMP=1,3
      COMPR=COMP
      IF(THGLAS(COMP,SIDE) .GT. 90.0) GO TO 78
      RTHGLA=THGLAS(COMP,SIDE)*PI/180.0
      INDEX=1.526
      SINRTH=SIN(RTHGLA)
      DESK=(SINRTH/INDEX)**2
      ABC=1.0-DESK
      CORE=SQRT(ABC)
      LDASH=THICK/CORE
      ABSORB=EXP(-1.*COEXT*LDASH)
      GLASTH=THGLAS(COMP,SIDE)
      REFLCT=REFL(GLASTH)
      TRANS(COMP,SIDE)=((1.0-REFLCT)**2)*ABSORB/(1.0-(REFLCT**2)*
     1(ABSORB**2))
      ALPHA(COMP,SIDE)=(1.0-REFLCT)-(((1.0-REFLCT)**2)*ABSORB/(1.0-
     1REFLCT*ABSORB))
      REFTOT(COMP,SIDE)=REFLCT+(REFLCT*((1.0-REFLCT)**2)*(ABSORB**2)/
     1(1.0-(REFLCT**2)*(ABSORB**2)))
      GO TO 188
78    ALPHA(COMP,SIDE)=0.0
      TRANS(COMP,SIDE)=0.0
      REFTOT(COMP,SIDE)=0.0
188   TOT(COMP,SIDE)=TRANS(COMP,SIDE)+ALPHA(COMP,SIDE)+REFTOT(COMP,SID
     1E)
550   CONTINUE
C     ****************************************************************
      TSOL(I,3,SIDE)=(ALPHA(1,SIDE)*IDIR(3,SIDE)+ALPHA(2,SIDE)*IDIF(3,
     2SIDE)+ALPHA(3,SIDE)*IREF(3,SIDE))/HOX(I)+TDB
      TRANSL(3,SIDE)=(TRANS(1,SIDE)*IDIR(3,SIDE)+TRANS(2,SIDE)*IDIF(3,
     2SIDE)+TRANS(3,SIDE)*IREF(3,SIDE))
      GO TO 600
500   ITOTAL(J,SIDE)=IDIR(J,SIDE)+IDIF(J,SIDE)+IREF(J,SIDE)
      TSOL(I,J,SIDE)=TDB+ALP(J)*ITOTAL(J,SIDE)/HOX(I)
C     ****************************************************************
600   CONTINUE
505   TSOL(I,4,SIDE)=TDB
      FOCO(PART)=FOCONV(PART)*3600.0
      IF(CASE .EQ. 2) GO TO 5555
C     ****************************************************************
C     CASE=1
      IF(J .EQ. 2) GO TO 444
      REC(I,J)=(1.0/HOX(I))+RESIST(J)
      YRW(1)=1.0;YRW(2)=2.0;YRW(3)=3.0
      ROP(I,J)=SDEF(J)*REC(I,J)*YRW(PART)
      CALL NEWTON(NR,IR,JR,SIDER,Y,EXPON,TEM,ROP,TSOL,DTEM)
      IF(DTEM(I,J,SIDE) .GT. 0) GO TO 422
      TYPE *,CASE,PART,ROUTE,PLACE,FLOMAS(M),I,J,SIDE,DTEM(I,J,S
     1IDE)
422   CONTINUE
```

```
      GO TO 75
444   V2=FLOMAS(M)*0.87/ADASH
      HIX(I,J,SIDE)=(0.0302*(V2**0.8)*(LEN**0.8)-57.6)/LEN
      GO TO 75
C     ************************************************************
C     CASE=2
5555  IF((J.EQ.2) .OR. (J.EQ.4)) GO TO 250
      HIX(I,J,SIDE)=0.237*(FOCO(PART)**0.5)*(LH**(-0.5))
      GO TO 75
250   HIX(I,J,SIDE)=(0.0302*(FOCO(PART)**0.8)*(LEN**0.8)-57.6)/LEN
75    REST(I,J,SIDE)=1.0/HIX(I,J,SIDE)+1.0/HOX(I)+RESIST(J)
      U(I,J,SIDE)=1.0/REST(I,J,SIDE)
C     ***************************************************
550   CONTINUE
450   CONTINUE
C     *********************************************************
      RC(I,1)=(U(I,1,1)*TSOL(I,1,1)+U(I,1,2)*TSOL(I,1,2))*COAREA
      RC(I,2)=(U(I,2,1)*TSOL(I,2,1)+U(I,2,2)*TSOL(I,2,2))*(PERIM-2.0*
     1LH-LW)/2.0
      RC(I,3)=(U(I,3,1)*TSOL(I,3,1)+U(I,3,2)*TSOL(I,3,2))*SOAREA
      RC(I,4)=(U(I,4,1)*TDB+U(I,4,2)*TDB)*(LW/2.0)
      S=(TRANGL(3,1)+TRANGL(3,2))*SOAREA
      R=RC(I,1)+RC(I,2)+RC(I,3)+RC(I,4)+S
      O=QTRIPL*AREA
      RD=R*1.1
      OD=O*1.1
      P=WTRIPL*AREA
      A=CPA+1.884*WINL
      F2=R+O-2501.4*P
      AMC(I,1)=(U(I,1,1)+U(I,1,2))*COAREA
      AMC(I,2)=(U(I,2,1)+U(I,2,2))*(PERIM-2.0*LH-LW)/2.0
      AMC(I,3)=(U(I,3,1)+U(I,3,2))*SOAREA
      AMC(I,4)=(U(I,4,1)+U(I,4,2))*(LW/2.0)
      AM=AMC(I,1)+AMC(I,2)+AMC(I,3)+AMC(I,4)
      AMD=AM*1.1
      F1=1.884*P+AM
      B=1.884*P
      FASD=(1.0+B*X(I+1)/(A*FLOMAS(M)))**(F1/B)
      TEM(I+1,N)=(F2-((F2-F1*TINL)/FASD))/F1
      TAVG(I,N)=(TEM(I,N)+TEM(I+1,N))/2.0
      IF(N .EQ. 1) GO TO 750
      DIFER=ABS(TEM(I+1,N)-TEM(I+1,N-1))
      IF(DIFER .LT. 0.01) GO TO 770
750   TEM(I,N+1)=TAVG(I,N)
      GO TO 1220
770   T(I+1)=TEM(I+1,N)
      GO TO 756
1220  CONTINUE
756   TMEAN(I)=(T(I)+T(I+1))/2.00
      W(I+1)=P*X(I+1)/FLOMAS(M)+WINL
      WMEAN(I)=(W(I)+W(I+1))/2.0
C     **************************************************************
      IF(CASE .EQ. 2) GO TO 400
      DT(I,1)=(DTEM(I,1,1)+DTEM(I,1,2))/2.0
      DT(I,3)=(DTEM(I,3,1)+DTEM(I,3,2))/2.0
      DT(I,4)=(DTEM(I,4,1)+DTEM(I,4,2))/2.0
      TWALL(I,1)=DT(I,1)+TMEAN(I)
      TWALL(I,3)=DT(I,3)+TMEAN(I)
      TWALL(I,4)=DT(I,4)+TMEAN(I)
      ASIDE=COAREA*LEN/23.0
      AGLASS=SOAREA*LEN/23.0
      AFLOOR=LW*LEN/23.0
      RADTEM(I)=(TWALL(I,1)*ASIDE+TWALL(I,3)*AGLASS+TWALL(I,4)*AFLOOR)
     1/(ASIDE+AGLASS+AFLOOR)
400   CONTINUE
C     ***************************************************************
      HEAT=U(I,2,1)*(TSOL(I,2,1)-TMEAN(I))
      TOWALL(I,2,1)=TSOL(I,2,1)-HEAT/HOX(I)
      TIWALL(I,2,1)=HEAT/HIX(I,2,1)+TMEAN(I)
             HEAT1=HOX(I)*(TSOL(I,2,1)-TOWALL(I,2,1))
             HEAT2=(TOWALL(I,2,1)-TIWALL(I,2,1))/RESIST(2)
             HEAT3=HIX(I,2,1)*(TIWALL(I,2,1)-TMEAN(I))
      GO TO(62,65,65,65),K
62    IF(VELOC.EQ.60 .OR. VELOC.EQ.120) GO TO 544
      GO TO 899
544   IF(PLACE .NE. 0) GO TO 899
      WRITE(41,780) PLACE,TDB,ITOTAL(2,1),I,XMEAN(I),TMEAN(I),TSOL(I
     1,2,1),TOWALL(I,2,1),TIWALL(I,2,1),HOX(I),HIX(I,2,1),RESIST(2),
     1U(I,2,1),HEAT1,HEAT2,HEAT3
899   CONTINUE
C     **************************************************************
65    CONTINUE
      QSTRU(I)=0
      QST1=(RC(I,1)-AMC(I,1)*TMEAN(I))*LEN/23.0
      QST2=(RC(I,2)-AMC(I,2)*TMEAN(I))*LEN/23.0
      QST3=(RC(I,3)-AMC(I,3)*TMEAN(I))*LEN/23.00
      QST4=(RC(I,4)-AMC(I,4)*TMEAN(I))*LEN/23.0
      QSTRIC(I)=QST1+QST2+QST3+QST4+S*LEN/23.0
```

```
      QTSTRU(I)=QSTRUC(I)+QTSTRU(I)
      QTRELE(I)=0
      QRELEA(I)=QTRIPL*AREA*LEN/23.0
      QTRELE(I)=QTRELE(I)+QRELEA(I)
      QTOTAL(I)=0
      QTOTAL(I)=QTSTRU(I)+QTRELE(I)
      WTRELE(I)=0.0
      WRELEA(I)=WTRIPL*AREA*LEN/23.0
      WTRELE(I)=WTRELE(I)+WRELEA(I)
      QTSTRU(I+1)=QTSTRU(I)
      QTRELE(I+1)=QTRELE(I)
      WTRELE(I+1)=WTRELE(I)
      QTOTAL(I+1)=QTOTAL(I)
C     *************************************************************
350   CONTINUE
C     ******************************************************************
      TEXIT=T(24)
      WEXIT=W(24)
      HINL=CPA*TINL+WINL*(2501.4+1.884*TINL)
      HEXIT=CPA*TEXIT+WEXIT*(2501.4+1.884*TEXIT)
      QH=FLOMAS(M)*(HEXIT-HINL)
      QTON=QH/12600.0
      WATADD=FLOMAS(M)*(WINL-WA)
      TON=QTOTAL(24)/12600.0
      LOAD=QTOTAL(24)
      TONSF=TON*1.1
      EVAPMW=FLOMAS(M)*(WEXIT-WINL)
      RISE=TEXIT-TINL
       AVGTEM=(TEXIT+TINL)/2.0
      PVEXIT=1.0132*WEXIT/(WEXIT+0.622)
      WAV=(WINL+WEXIT)/2.0
      PVTAV=1.0132*WAV/(WAV+0.622)
      PSEXIT=PS(TEXIT)
      RHEXIT=PVEXIT/PSEXIT
      MA(M)=FLOMAS(M)
C     ****************************************************************
C     CALCULATION OF AIR WASHER DIMENSIONS
C     ****************************************************************
      HDAV=5000.0
      VFACE=2.4*3600.0
      SPVOLA=287.2*(TDB+273.16)/((1.0132-PV(TDB,TWB))*1.0E05)
      FLOW(M)=FLOMAS(M)*SPVOLA
      Z=-ALOG(1.0-EFF)
      VOLAW=FLOMAS(M)*Z/HDAV
      AFACE=FLOW(M)/VFACE
      LENAW=VOLAW/AFACE
C     ****************************************************************
C     CALCULATION OF COMFORT VELOCITY BY FANGER'S EQUATION
C     ***************************************************************
      IF(CASE .EQ. 2) GO TO 111
      MRT=(RADTEM(1)+RADTEM(23))/2.0
111   MRT=AVGTEM
      CALL FANGER(METAB,WEFF,MRT,ADU,FCL,ICL,PVTAV,AVGTEM,HC)
      COMFV=(HC/10.4)**2
C     ***********************************************************
C     CALCULATION OF DUCT DIMENSIONS AND BLOWER HP
C     ***********************************************************
      WDMM=300.0
      HDMM=200.0
      WDM=WDMM/1000.0
      HDM=HDMM/1000.0
      FR1=WDM*HDM
      FR2=WDM+HDM
      DIA=1.265*(FR1**3/FR2)**0.2
      ROUGH=1.0/1000.0
      FACT=1.0/(1.74-2.0*ALOG(2.0*ROUGH/DIA))
      VDUCT=FLOW(M)/(FR1*3600.0)
      PDROP=FACT*(LEN/DIA)*(1.0/SPVOLA)*(VDUCT**2)/(2.0*9.81)
      POWER=PDROP*FLOW(M)/(3600.0*75.0)
      IFLOW(M)=FLOW(M)
      IVFACE=VFACE
      IQH=QH
C     ***********************************************************
207   FORMAT(1X,'HEXTSET',2X,'ROUTE=',I2/25('*')/)
      WRITE(45,12),PLACE,TDB,TWB,MA(M),EFF,TINL,TEXIT,AVGTEM,RISE,
     1QTSTRU(24),QTRELE(24),LOAD,TON,TONSF,WATADD,POWER,QTON,X(1),T(1
     1),X(12),T(12),X(23),T(23)
12    FORMAT(5X,I2,2(1X,F4.1),6X,I5,1X,F4.2,3X,F4.1,2(1X,F4.1),3X,F4.1
     1,2X,I7,1X,I5,1X,I6,1X,F4.2,3X,F4.2,4X,F6.2,1X,
     1F5.1,2X,F4.1,7X,F5.2,2X,F4.1,5X,F5.2,2X,F4.1,5X,F5.2,2X,F4.1)
      WRITE(46,13),PLACE,TDB,TWB,WA,RHTDB,MA(M),TINL,WINL,RHINL,TEXIT,
     1WEXIT,RHEXIT,WATADD,MRT,COMFV,HINL,HEXIT,IQH,QTON,TON
13    FORMAT(5X,I2,4X,F4.1,4X,F4.1,1X,F6.4,1X,F5.2,5X,I5,2X,F4.1,1X,
     1F6.4,1X,F5.2,4X,F4.1,1X,F6.4,3X,F5.2,5X,F6.2,2X,F6.1,4X,F6.1,
     12(2X,F5.1),2X,I6,2(2X,F4.2))
      WRITE(47,14),PLACE,TDB,TWB,MA(M),SPVOLA,EFF,IFLOW(M),IVFACE,
     1LENAW,AFACE,VOLAW,WATADD
14    FORMAT(5X,I2,4X,F4.1,4X,F4.1,6X,I5,3X,F4.2,1X,F4.2,4X,I6,9X,I4,
     12X,F5.2,1X,F5.2,2X,F6.2,4X,F6.2)
```

```
     IWDM,POWER
15   FORMAT(5X,I2,2(4X,F4.1),6X,I5,7X,F6.1,5X,I6,6X,F6.1,3X,F6.2,2X
    1,F4.2,3X,F4.2,3X,F6.1)
788  FORMAT(2X,I2,5X,F4.1,4X,F6.1,4X,I2,4X,F5.2,4(4X,F4.1),4X,F6.2,
    14X,F5.2,F7.4,2X,F6.2,3(2X,F6.2))
C    ***************************************************************
88   CONTINUE
2000 CONTINUE
1000 CONTINUE
412  CONTINUE
     STOP
     END
C    ***********************************************************
C    SUBPROGRAM 1 FOR TIME
C         ***********************************************************
     FUNCTION TIME(LAPPTM,NOON)
     REAL LAPPTM,NOON
     INTEGER TIME
     IF(LAPPTM .LT. NOON) GO TO 1
     CONTINUE
     IF(LAPPTM .GT. NOON) GO TO 2
     CONTINUE
     IF(LAPPTM .EQ. NOON) GO TO 3
1    TIME=1
     RETURN
2    TIME=2
     RETURN
3    TIME=3
     RETURN
     END
C    ************************************************************
C    SUBPROGRAM 2 FOR PV
C    *******************************************************
     FUNCTION PV(TPROB,TPRWB)
     PV=PS(TPRWB)-(1.0132-PS(TPRWB))*(TPROB-TPRWB)/(1547.-1.44*TPRWB)
     RETURN
     END
C    **************************************************************
C    SUBPROGRAM 3 FOR PS
C    **************************************************************
     FUNCTION PS(TC)
     TK=TC+273.16
     DK=EXP((7.21379+(1.1520E-05-4.787E-09*TK)*(TK-483.16)**2)*
    1(647.31/TK-1.0))
     PSATA=225.65/DK
     PSBAR=PSATA/1.02
     PS=PSBAR
     RETURN
     END
C    ************************************************************
C    SUBPROGRAM 4   AT FOR TILT ANGLE OF SURFACE
C    ***************************************************************
     REAL FUNCTION AT(BJR,BSIDER)
     INTEGER BJR,BSIDER
     PI=3.1415926
     IF((BJR .EQ. 2) .AND. (BSIDER.EQ.1 .OR. BSIDER.EQ. 2)) GO TO 21
     CONTINUE
     IF((BJR .EQ. 1 .OR. BJR .EQ. 3) .AND. (BSIDER .EQ. 1 .OR. BSIDER
    1 .EQ. 2)) GO TO 20
21   AT=0
     RETURN
20   AT=90.0*PI/180.0
     RETURN
     END
C    ***************************************************************
C    FUNCTION SUBPROGRAM 5  AG FOR GAMMA ANGLE
C    ***************************************************************
     FUNCTION AG(BSIDER,BIT,BSIGH,BPHI,BLAT,BDEC)
     INTEGER BSIDER,BIT
     DIMENSION BSIGH(2)
     IF(BIT.EQ.3) GO TO 35
     CONTINUE
     IF(BSIDER.EQ.1 .AND. BIT.EQ.1) GO TO 30
     CONTINUE
     IF(BSIDER.EQ.2 .AND. BIT.EQ.1) GO TO 31
     CONTINUE
     IF(BSIDER.EQ.1 .AND. BIT.EQ.2) GO TO 32
     CONTINUE
     IF(BSIDER.EQ.2 .AND. BIT.EQ.2) GO TO 33
30   AG=ABS(BPHI-BSIGH(BSIDER))
     RETURN
31   AG=BPHI+BSIGH(BSIDER)
     RETURN
32   AG=BPHI+BSIGH(SIDER)
     RETURN
33   AG=ABS(BPHI-BSIGH(SIDER))
     RETURN
35   IF(BLAT .GT. BDEC) GO TO 34
```

```
      AG=180.0
      RETURN
34    AG=0
      RETURN
      END
C     ******************************************************************
C     FUNCTION SUBPROGRAM 6 FOR  FSS
C     ***************************************************************
      FUNCTION FSS(BJR,BSIDER,BRTHET)
      INTEGER BJR,BSIDER
      DIMENSION BRTHET(4,2)
      IF(BJR .EQ. 2) GO TO 91
      COSRTH=COS(BRTHET)
      IF(COSRTH .GT. -0.2) GO TO 92
      FSS=0.45
      RETURN
92    FSS=0.55+0.437*COSRTH+0.313*(COSRTH**2)
      RETURN
91    FSS=1.0
      RETURN
      END
C     ****************************************************************
C     FUNCTION SUBPROGRAM 7 FOR FSG
C     ******************************************************************
      FUNCTION FSG(BJR,BSIDER)
      INTEGER BJR,BSIDER
      IF(BJR .EQ. 2) GO TO 85
      FSG=0.5
      RETURN
85    FSG=0
      RETURN
      END
C     ******************************************************************
C     FUNCTION PROGRAM 8 FOR REFL OF GLASS(INTERPOLATED)
C     LAGRANGIAN INTERPOLATION FOR THGLAS > 50.0
C     LINEAR INTERPOLATION FOR THGLAS</= 50.0
C     ******************************************************************
      FUNCTION REFL(GLASST)
      REAL L0,L1,L2,L3,L4
      IF(GLASST .LE. 50.0) GO TO 75
      L0=(GLASST-60.0)*(GLASST-70.0)*(GLASST-80.0)*(GLASST-90.0)
      L1=(GLASST-50.0)*(GLASST-70.0)*(GLASST-80.0)*(GLASST-90.0)
      L2=(GLASST-50.0)*(GLASST-60.0)*(GLASST-80.0)*(GLASST-90.0)
      L3=(GLASST-50.0)*(GLASST-60.0)*(GLASST-70.0)*(GLASST-90.0)
      L4=(GLASST-50.0)*(GLASST-60.0)*(GLASST-70.0)*(GLASST-80.0)
      REFL=0.06*L0/(24.E4)-0.09*L1/(6.E4)+0.165*L2/(4.E4)-0.38*L3/
     1(6.E4)+1.0*L4/(24.E4)
      RETURN
75    REFL=0.02+(8.0E-4)*GLASST
      RETURN
      END
C     ******************************************************************
C     SUBROUTINE NEWTON FOR OTEN;NEWTON-RAPHSON METHOD OF ITERATION
C     ******************************************************************
      SUBROUTINE NEWTON(BNR,BIR,BJR,BSIDER,BY,BEXPON,BT,BROP,BTSOL,
     1SOLN)
      INTEGER BNR,BIR,BJR,BSIDER
      DIMENSION BY(4),BEXPON(4),BT(25,50),BROP(25,4),BTSOL(25,4,2),
     1SOLN(25,4,2)
      Z1=20.0
      MAXIT=10
      DO 44 INDIC=1,MAXIT
      FUNC=Z1+BROP(BIR,BJR)*(Z1**BY(BJR))-BTSOL(BIR,BJR,BSIDER)+BT(BIR
     1,BNR)
      FDIF=1.0+BY(BJR)*BROP(BIR,BJR)*(Z1**BEXPON(BJR))
      Z2=Z1-(FUNC/FDIF)
      IF(ABS(Z2-Z1) .LE. 0.01) GO TO 11
      Z1=Z2
44    CONTINUE
11    SOLN(BIR,BJR,BSIDER)=Z2
      RETURN
      END
C     ***************************************************************
C     SUBROUTINE FANGER FOR COMFORT VELOCITY
C     ************************************************************
      SUBROUTINE FANGER(META,WORK,MRTEMP,AD,FC,IC,PVAVG,TEMAV,HCS)
      REAL META,MRTEMP,IC,METAS
      METAS=META/4.187
      FON=METAS*(1.0-WORK)/AD
      RIN=METAS/AD
      PVAHG=PVAVG*760.0/1.0132
      SLEFT=FON-0.35*(43.0-0.061*FON-PVAHG)-0.42*(FON-50.0)-0.0023*
     1RIN*(44.0-PVAHG)-0.0014*RIN*(34.0-TEMAV)
      TCL=35.7-0.032*FON-0.18*IC*SLEFT
      RDF=SLEFT-3.4E-08*((TCL+273.0)**4-(MRTEMP+273.0)**4)*FC
      HCS=RDF/(FC*(TCL-TEMAV))
      RETURN
      END
```

```
C     *******************************************************************
C     PROGRAM FORCOOLING LOADCALCULATIONS IN AN EVAP.COOLED RLYCOACH
C     AND RECIRCULATION OF EXIT AIR OF COACH
C     *******************************************************************
C     PLACE=11-KANPUR;21-CHANDIGARH;0-DELHI;;34-BARODA
C            22-BHOPAL;23-NAGPUR;24-HYDERABAD;12-ALLAHABAD;13-PATNA
C        14-JAMSHEDPUR ,31-JODHPUR;32-JAIPUR;33-AHMEDABAD
C     ROUTE=CODE FOR DIRECTIONS OF THE MOVING COACH
C            1   FOR N-SE OR N-NW
C            2   FOR N-S OR N-S
C            3   FOR NE-SW  OR SW-NE
C     MONTH=5 FOR MAY
C          =7 FOR AUG
C     IT=1 BEFORE  SOLAR NOON
C         =2 AFTER SOLAR NOON
C     =3 AT SOLAR NOON
C     SIDE=1 FOR EAST FACING SIDE OF COACH
C         =2 FOR WEST FACING SIDE OF COACH
C     ANGLES:LAT-LATITUDE ANGLE,DEC-DECLINATION ANGLE,HOUR-HOUR ANGLE
C     SIGH-SURFACE AZIMUTH ANGLE MEASURED FROM SOUTH(ASHRAE 1981)
C     TILT-INCL.ANGLE OF SURFACE MEASURED UPWARD FROM HORIZONTAL
C     PHI-SOLAR AZIMUTH ANGLE MEASURED FROM SOUTH
C     GAM-SURFACE-SOLAR AZIMUTH ANGLE;BETA-ALTITUDE ANGLE
C     THETA-INCIDENCE ANGLE
C     LEN=LENGTH OF THE COACH;LW=WIDTH;LH=HEIGHT
C     *******************************************************************
      REAL LEN,LH,LW,IDN,IDIR(3,2),IDIF(3,2),IREF(3,2),ITOTAL(2,2),
     1LAT,COAST,KGLASS,INDEX,IST,ISTH,ISTM,NOON,LAPPTM,LMT,LENAW,MRT,
     1ICL,METAB,MOIST
      INTEGER PLACE,MONTH,DIRN,SIDE,SIDER,COMP,COMPR,DAY,V,VR,
     1OTSTRU(25),OTOTAL(25),OTRELE(25),ROUTE,VELOC,TIME,CASE,PART
C     *******************************************************************
      DIMENSION X(25),T(25),TMEAN(25),Y(4),EXPON(4),ALP(2),COEF(4),
     1SIGH(2),RTHETA(4,2),TRGLAS(4,2),TRANS(4,2),RADTEM(25),TWALL(25,
     14),ALPHA(4,2),REFTOT(4,2),TOT(4,2),AMC(25,4),RC(25,4),
     1ORELEA(25),WRELEA(25),OSTRUC(25),W(25),DT(25,4),YRW(3),
     1WTRELE(25),RFC(25,4),ROP(25,4),DTEM(25,4,2),XMEAN(25),HIX(25
     1,4,2),HOX(25),RESIST(4),U(25,4,2),FSOL(25,4,2),TRANGL(4,2),
     1REST(24,4,2),FLOMAS(5),MA(5),IFLOW(5),FLOW(5),FOCONV(5),
     1HEEFF(3),RECIRC(3),FOCO(3),TPR(100),TEM(25,20),TAVG(25,20),
     1TOWALL(25,4,3),TIWALL(25,4,3)
C     *******************************************************************
      OPEN(UNIT=30,DEVICE='DSK',FILE='KANPUR.FOR')
      OPEN(UNIT=31,DEVICE='DSK',FILE='DATA.FOR')
      OPEN(UNIT=32,DEVICE='DSK',FILE='TIME.DAT')
      OPEN(UNIT=40,DEVICE='DSK',FILE='ANGLE.DAT')
      OPEN(UNIT=41,DEVICE='DSK',FILE='INTENS.DAT')
      OPEN(UNIT=45,DEVICE='DSK',FILE='TON2.DAT')
      OPEN(UNIT=46,DEVICE='DSK',FILE='COMF2.DAT')
      OPEN(UNIT=47,DEVICE='DSK',FILE='WASH2.DAT')
      OPEN(UNIT=48,DEVICE='DSK',FILE='DUCT2.DAT')
      OPEN(UNIT=49,DEVICE='DSK',FILE='FOR49.DAT')
C     IST=INDIAN STANDARD TIME;LOCAL APPARENT TIME=LOCAL SOLAR TIME
C     *******************************************************************
      READ(31,*),(FLOMAS(M),M=1,4)
      VELOC=60
      MOIST=0.100
      DAY=21
      MONTH=5
      IST=12.00
      FOCONV(1)=0.50;FOCONV(2)=0.75;FOCONV(3)=1.00
      HEEFF(1)=0.60;HEEFF(2)=0.70;HEEFF(3)=0.80
      RECIRC(1)=0.50;RECIRC(2)=0.65;RECIRC(3)=0.80
C     *******************************************************************
      WRITE(45,10)
      WRITE(49,10)
      WRITE(41,10)
      WRITE(46,10)
      WRITE(47,10)
      WRITE(48,10)
      WRITE(45,60)
      WRITE(46,60)
      WRITE(47,60)
      WRITE(49,60)
      WRITE(41,60)
      WRITE(48,60)
      WRITE(45,100),DAY,MONTH,IST,VELOC,MOIST
      WRITE(41,100),DAY,MONTH,IST,VELOC,MOIST
      WRITE(46,100),DAY,MONTH,IST,VELOC,MOIST
      WRITE(47,100),DAY,MONTH,IST,VELOC,MOIST
      WRITE(48,100),DAY,MONTH,IST,VELOC
```

```
      WRITE(13,813)
C     ************************************************************
      DO 112 ROF=1,1
      READ(30,*),ROUTE,PLACE,LAT,TDB,TWB,SIGH(1),SIGH(2),DEGLON,MINLON
     1,IDAY
C     ************************************************************
      DO 5500 K=1,1
      DO 5500 NFW=1,1
      WRITE(45,207),ROUTE,BEEFF(K),RECIRC(NFW)
      WRITE(46,207),ROUTE,BEEFF(K),RECIRC(NFW)
      WRITE(47,207),ROUTE,BEEFF(K),RECIRC(NFW)
      WRITE(48,207),ROUTE,BEEFF(K),RECIRC(NFW)
      WRITE(11,207),ROUTE,BEEFF(K),RECIRC(NFW)
      DO 1500 CASE=1,2
      DO 2000 PART=1,3,2
C     ************************************************************
C     O U T P U T   F O R M A T   S T A T E M E N T S
60    FORMAT(5X,'W I T H     R E G E N E R A T I O N'/5X,25('=')/)
      IF(CASE.EQ. 1) GO TO 1050
      GO TO 4
1050  GO TO(1,2,3),PART
1     WRITE(45,70)
      WRITE(46,70)
      WRITE(47,70)
      WRITE(48,70)
      GO TO 1222
70    FORMAT(5X,'CASE-I-A FREE CONVECTION ONCE AT SIDES AND FLOOR'/
     15X,40('=')/)
2     WRITE(45,80)
      WRITE(46,80)
      WRITE(47,80)
      WRITE(48,80)
      GO TO 1222
80    FORMAT(5X,'CASE-I-B FREE CONVECTION TWICE AT SIDES AND FLOOR'/
     15X,40('=')/)
3     WRITE(45,90)
      WRITE(46,90)
      WRITE(47,90)
      WRITE(48,90)
      GO TO 1222
90    FORMAT(5X,'CASE-I-C FREE CONVECTION THRICE AT SIDES AND FLOOR'/
     15X,40('=')/)
4     WRITE(45,125),FOCONV(PART)
      WRITE(46,125),FOCONV(PART)
      WRITE(47,125),FOCONV(PART)
      WRITE(48,125),FOCONV(PART)
125   FORMAT(5X,'CASE-II FORCED CONVECTION AT ALL SIDES OF COACH WITH
     1 VELOCITY(M/S)= ',F4.2/5X,70('=')/)
100   FORMAT(40X,'DAY=',I2,2X,'MONTH=',I2,2X,'IST=',F5.2/35X,42('=')//
     145X,'VELOCITY OF COACH(KMS/H)=',I3/45X,17('=')//25X,'MOISTURE
     1 RELEASE(KG/H-PERSON)='F5.3/25X,50('='))
101   FORMAT(25X,'COOLING LOADS AND TEMPERATURE RISE'/25X,45('=')/)
102   FORMAT(25X,'COACH CONDITIONS FOR THERMAL COMFORT'/25X,50('=')/)
103   FORMAT(25X,'AIR WASHER DIMENSIONS'/25X,25('=')/)
104   FORMAT(25X,'DUCT DIMENSIONS AND BLOWER POWER'/25X,55('=')/)
8905  FORMAT(2X,100('=')/2X,'ITER',2X,'MA(KG/H)',4X,'TDB',5X,'TWB',
     14X,'TDB1-C',5X,'TWB1-C',5X,'TINL',5X,'TEXIT',4X,'AVGTEM',4X,
     1'DELT',4X,'TON',4X,'TONSF',4X,'QT',4X,'U(1,2,1)',2X,'TSOL
     1(1,2,1)',4X,'XMEAN(1)',4X,'TMEAN(1)',4X,'U(23,2,1)',4X,'TSOL(23
     1,2,1)',
     14X,'XMEAN(23)',4X,'TMEAN(23)'/2X,105('='))
810   FORMAT(2X,100('=')/2X,'PLACE',1X,'TDB-C',1X,'TWB-C',1X,'TDB1-C',
     11X,'TWB1-C',1X,'MA(KG/H)',2X,'EFF',
     13X,'TINL',3X,'TEXIT',2X,'AVGTEM',3X,'DELT',3X,'QSTRUCT',
     14X,'QR',3X,'LOAD',2X,'TON',3X,'TONSF',2X,'MW(KG/H)',2X,'P(HP)',
     12X,'QTON',7X,'X(3)',2X,'T(3)',5X,'X(12)',5X,'T(12)',5X,'X(20)',
     15X,'T(20)'/2X,100('='))
811   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'RHTDB',2X,'MA(KG/H)'
     12X,'TDB1',2X,'TWB1',2X,'RHTDB1'3X,'EFF',4X,'TINL',2X,'RHINL',2X
     1,'TEXIT',2X,'RHEXIT',3X,'WA',2X,'WTDB1',4X,'WINL',4X,'WEXIT'
     12X,'MRT(C)',2X,'COMFV(M/S)'/
     12X,100('='))
812   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'MA(KG/H)',2X,'SPVOL'
     1,2X,'EFF',2X,'Q(CUM/H)',2X,'FACEV(M/H)',3X,'L(M)',3X,'A(SQM)',2
     1X,'R(CUM)',2X,'MW(KG/H)'/2X,100('='))
813   FORMAT(2X,'PLACE',3X,'TDB-C',3X,'TWB-C',3X,'MA(KG/H)',3X,'VDUCT
     1(M/S)',3X,'Q(CUM/H)',3X,'PDROP(MM)',3X,'DIA(M)',2X,'H(M)',3X,
     1'W(M)',4X,'P(HP)'/2X,100('='))
C     ************************************************************
1222  CONTINUE
```

```
      EDTIME=3.0+37.0/60.0
      NOON=12.0+00.3
      LAPPTM=LAPTEDTIME
      IT=FIXE(LAPPTM,NOON)
      HOUR=ABS(100.-LAPPTM)/4.0
C     ****************************************************************
10    FORMAT(5X,80('=')/10X,'CODES:  ROUTE(1-J-SE)-DELHI-(0),KANPUR-
     1(11),AHMADABAD-(12),PATNA-(13),JAMSHEDPUR-(14)'/19X,'ROUTE(2-N-
     1-S)-CHANDIGARH-(21),DELHI-(0),BHOPAL-(22),NAGPUR-(23),HYDERABAD
     1-(24)'/19X,'ROUTE(3-S-SW)-DELHI(0),JODHPUR-(31),JAIPUR-(32),AHM
     1EDABAD-(33),[illegible]A-(33)'/5X,80('='))
C     ****************************************************************A532
      VEL=V[illegible]
      DO [illegible] =1,3
      DO 1500 [illegible]R=1,20
      DEC=2[illegible]
      A=1[illegible]
      B=0.14[illegible]
      C=0.121
      EFF=0.75
      PI=3.1415926
      RLAT=LAT*PI/180.0
      RDEC=DEC*PI/180.0
      RHOUR=HOUR*PI/180.0
      RBETA=ASIN(COS(RLAT)*COS(RHOUR)*COS(RDEC)+SIN(RLAT)*SIN(RDEC))
      BETA=RBETA*180.0/PI
      MR=1
      IF(ITER .EQ. 1) GO TO 1211
      TDB1=TDB-HCEFF(K)*RECIRC(NFW)*(TDB-TEXIT)
      PV1=PV(TDB,TWB)
      CALL WETTSW(TDB1,PV1,TWB1)
      TDRY=TDB1
      TWET=TWB1
      GO TO 1305
1211  TDRY=TDB
      TWET=TWB
1305  TINL=TDRY*(1.0-EFF)+TWET*EFF
      TPR(ITER)=TDRY
      WA=0.622*PV(TDB,TWB)/(1.0132-PV(TDB,TWB))
      WTDB1=WA
      WINL=0.622*PV(TINL,TWB)/(1.0132-PV(TINL,TWB))
      RHTDB=PV(TDB,TWB)/PS(TDB)
      RHTDB1=PV(TDB1,TWB1)/PS(TDB1)
      RHINL=PV(TINL,TWB)/PS(TINL)
      T(1)=TINL
      W(1)=WINL
      IF(IP .EQ. 3) GO TO 1445
      RPHI=ACOS((SIN(RBETA)*SIN(RLAT)-SIN(RDEC))/(COS(RBETA)*COS(RLAT)
     1))
      PHI=RPHI*180.0/PI
      GO TO 2010
1445  PHI=0.0
2010  SINBET=SIN(RBETA)
      IDN=(A/EXP(B/SINBET))*3.6
      CPA=1.004
      ****************************************************************
      VALUES OF VA IOUS COACH PA RAMETE RS A RE GIVEN BELOW
      GEN.FORM OF HI=COEF*(DTEM)**EXPON;DTEM=TWI-T;T=TEMP INSIDE COACH
      COACH DIVIDED INTO 23 SECTIONS;NOOF PERSONS=76;NOOF WINDOWS ON
      ONE SIDE=23,SENS.HT.RELEASE=440KJ/HR/PERSON;LATNT=65 GMS WATER/H
      R/PERSON;AREA=AREA OF X-SECTION;PERIM=PERIMETER OF X-SECTION
      CLOTHING OF PERSONS-TROPICAL LIGHT SUMMER CLOTHING
      LEN=21.337
      LW=3.061
      LH=2.075
      PERSON=76.0
      WINDOW=23.0
      AREA=7.533
      PERIM=10.665
      VOL=AREA*LEN
      METAB=440.0
      FCL=1.1
      ICL=0.50
      ADASH=2.427
      ADU=1.[illegible]
      N[illegible]=0.0
      QTRIPL=METAB*PERSON/VOL
      WT[illegible]L=[illegible]PERSON/VOL
      [illegible]=9.81*0.60
      S[illegible]=(WINDOW/LEN)*AREMIA
```

```
      RHOG=0.20
C     VALUES OF STRUCTURE RESISTANCES GIVEN BELOW
C     ST...  WINDOW GLASS (QUALITY-DOUBLE STRENGTH) USED FOR COACH
C              THICKNESS OF ABOVE GLASS=0.125 INCH=3.048
C     CONDUCTIVITY OF GLASS=2.49 KJ/HR-M-C=0.4 BTU/HR-FT-F
      TGLASS=0.125*25.4*1.0E-3
      KGLASS=2.49
      RESIST(1)=0.0560;RESIST(2)=0.0704;RESIST(4)=0.1133
      RESIST(3)=TGLASS/KGLASS
C     FLOMAS=MASS FLOW RATE OF AIR IN KG/HR
C     M=1,FLOMAS=10000,M=2-15000,M=3-20000,M=4-25000,M=5-30000KG/HR
C     VED = EFFECTIVE VELOCITY OF MOVING COACH CONSIDERING WIND SPEED
C     V=1,VED(V)=30000M/HR;V=2-60000M/HR;V=3-90000M/HR;V=4-120000M/HR
C     ******************************************************************
C     *******************************************************************
      DO 35  I=1,23
      IP=I
C     CALCULATION OF HDX FOR TURBULENT FLOW AT VARIOUS XMEAN
      X(I+1)=X(I)+LEN/23.0
      XMEAN(I)=(X(I)+X(I+1))/2.0
        HDX(I)=0.0243*(VEL**0.8)*(XMEAN(I)**(-0.2))
      DO 1220 N=1,20
      NP=N
      TEM(I,1)=T(1)
      DO 150 J=1,4
      DO 550 SIDE=1,2
      SIDER=SIDE
      JR=J
      IF(J .EQ. 4) GO TO 505
      RTILT=AT(JR,SIDER)
      TILT=RTILT*(180.0/PI)
      IF(J .EQ. 2) GO TO 677
      GAM=AG(SIDER,IT,SIGH,PHI,LAT,DEC)
      RGAM=GAM*(PI/180.0)
      RTHETA(J,SIDE)=ACOS(COS(RBETA)*COS(RGAM))
      GO TO 224
677   RTHETA(J,SIDE)=ACOS(SIN(RBETA))
      IDIR(J,SIDE)=IDN*COS(RTHETA(J,SIDE))
224   CONTINUE
      THETA=RTHETA(J,SIDE)*(180.0/PI)
C     ***************************************************************
      IF(J .EQ. 2 ) GO TO 221
      IF(GAM .GT. 90.0) GO TO 55
      IDIR(J,SIDE)=IDN*COS(RTHETA(J,SIDE))
      GO TO 56
55    IDIR(J,SIDE)=0
221   CONTINUE
56    IDIF(J,SIDE)=IDN*C*FSS(JR,SIDER,RTHETA)
      IREF(J,SIDE)=IDN*RHOG*FSG(JR,SIDER)*(C+SINBET)
C     ****************************************************************
      IF(J .EQ. 1 .OR. J .EQ. 2) GO TO 500
      THGLAS(1,SIDE)=RTHETA(3,SIDE)*180.0/PI
      THGLAS(2,SIDE)=60.0
      THGLAS(3,SIDE)=50.0
      COEXT=0.194
      THICK=0.125
      DO 650 COMP=1,3
      COMPR=COMP
      IF(THGLAS(COMP,SIDE) .GT. 90.0) GO TO 78
      RTHGLA=THGLAS(COMP,SIDE)*PI/180.0
      INDEX=1.526
      SINRTH=SIN(RTHGLA)
      DESK=(SINRTH/INDEX)**2
      ABC=1.0-DESK
      CORE=SQRT(ABC)
      LDASH=THICK/CORE
      ABSORB=EXP(-1.*COEXT*LDASH)
      GLASTH=THGLAS(COMP,SIDE)
      REFLCT=REFL(GLASTH)
      TRANS(COMP,SIDE)=((1.0-REFLCT)**2)*ABSORB/(1.0-(REFLCT**2)*
     1(ABSORB**2))
      ALPHA(COMP,SIDE)=(1.0-REFLCT)-(((1.0-REFLCT)**2)*ABSORB/(1.0-
     1REFLCT*ABSORB))
      REFTOT(COMP,SIDE)=REFLCT+(REFLCT*((1.0-REFLCT)**2)*(ABSORB**2)/
     1(1.0-(REFLCT**2)*(ABSORB**2)))
      GO TO 198
78    ALPHA(COMP,SIDE)=0.0
      TRANS(COMP,SIDE)=0.0
      REFTOT(COMP,SIDE)=0.0
      ...(COMP,SIDE)=TRANS(COMP,SIDE)+ALPHA(COMP,SIDE)+REFTOT(COMP...
```

```
500       [illegible](I,SIDE)=[illegible](J,SIDE)

          TSOL(I,J,SIDE)=FDB+ALP(J)*ITOTAL(J,SIDE)/HOX(I)
C         ****************************************************************
600       CONTINUE
505       TSOL(I,4,SIDE)=FDB
          IF(CASE .EQ. 2) GO TO 5555
          IF(J .EQ. 2) GO TO 444
          REC(I,J)=(1.0/HOX(I))+RESIST(J)
          YRW(1)=1.0;YRW(2)=2.0;YRW(3)=3.0
          ROP(I,J)=COEF(J)*REC(I,J)*YRW(PART)
          CALL [illegible](OR,IR,JR,SIDER,Y,EXPON,TEM,ROP,TSOL,DTEM)
          IF(DTEM(I,J,SIDE) .GT. 0) GO TO 477
          TYPE *,CASE,PART,ROUTE,PLACE,FLOMAS(M),I,J,SIDE,DTEM(I,J,SI
          1DE)
477       HIX(I,J,SIDE)=COEF(J)*(DTEM(I,J,SIDE)**EXPON(J))*YRW(PART)
          GO TO 75
444       V2=FLOMAS(M)*0.87/ADASH
          HIX(I,J,SIDE)=0.0247*(V2**0.8)*(XMEAN(I)**(-0.2))
          GO TO 75
5555      IF((J.EQ.2) .OR. (J.EQ.4)) GO TO 250
          FOCO(PART)=FUCONV(PART)*3600.0
          HIX(I,J,SIDE)=0.0247*(FOCO(PART)**0.8)*(LH**(-0.2))
          GO TO 75
250       HIX(I,J,SIDE)=0.0247*(FOCO(PART)**0.8)*(XMEAN(I)**(-0.2))
75        REST(I,J,SIDE)=1.0/HIX(I,J,SIDE)+1.0/HOX(I)+RESIST(J)
          U(I,J,SIDE)=1.0/REST(I,J,SIDE)
C         ****************************************************************
550       CONTINUE
450       CONTINUE
C         ****************************************************************
          RC(I,1)=(U(I,1,1)*TSOL(I,1,1)+U(I,1,2)*TSOL(I,1,2))*COAREA
          RC(I,2)=(U(I,2,1)*TSOL(I,2,1)+U(I,2,2)*TSOL(I,2,2))*(PERIM-2.0*
          1LH-LW)/2.0
          RC(I,3)=(U(I,3,1)*TSOL(I,3,1)+U(I,3,2)*TSOL(I,3,2))*SOAREA
          RC(I,4)=(U(I,4,1)*FDB+U(I,4,2)*FDB)*(LW/2.0)
          S=(TRANGL(3,1)+TRANGL(3,2))*SOAREA
          R=RC(I,1)+RC(I,2)+RC(I,3)+RC(I,4)+S
          Q=SERIPL*AREA
          RD=R*1.1
          QD=Q*1.1
          P=WTRIPL*AREA
          A=CPA+1.884*WINL
          F2=R+Q-2501.4*P
          AMC(I,1)=(U(I,1,1)+U(I,1,2))*COAREA
          AMC(I,2)=(U(I,2,1)+U(I,2,2))*(PERIM-2.0*LH-LW)/2.0
          AMC(I,3)=(U(I,3,1)+U(I,3,2))*SOAREA
          AMC(I,4)=(U(I,4,1)+U(I,4,2))*(LW/2.0)
          AM=AMC(I,1)+AMC(I,2)+AMC(I,3)+AMC(I,4)
          AMD=AM*1.1
          F1=1.884*P+AM
          B=1.884*P
          FASD=(1.0+B*X(I+1)/(A*FLOMAS(M)))**(F1/B)
          TEM(I+1,N)=(F2-((F2-F1*TINL)/FASD))/F1
          TAVG(I,N)=(TEM(I,N)+TEM(I+1,N))/2.0
          IF(N .EQ. 1) GO TO 750
          DIFER=ABS(TEM(I+1,N)-TEM(I+1,N-1))
          IF(DIFER .LT. 0.01) GO TO 770
750       TEM(I,N+1)=TAVG(I,N)
          GO TO 1220
770       T(I+1)=TEM(I+1,N)
          GO TO 756
1220      CONTINUE
756       TMEAN(I)=(T(I)+T(I+1))/2.00
          W(I+1)=P*X(I+1)/FLOMAS(M)+WINL
C         ****************************************************************
          IF(CASE .EQ. 2) GO TO 400
          DT(I,1)=(DTEM(I,1,1)+DTEM(I,1,2))/2.0
          DT(I,3)=(DTEM(I,3,1)+DTEM(I,3,2))/2.0
          DT(I,4)=(DTEM(I,4,1)+DTEM(I,4,2))/2.0
          TWALL(I,1)=DT(I,1)+TMEAN(I)
          TWALL(I,3)=DT(I,3)+TMEAN(I)
          TWALL(I,4)=DT(I,4)+TMEAN(I)
          ASIDE=COAREA*LEN/23.0
          AGLASS=SOAREA*LEN/23.0
          AFLOOR=LW*LEN/23.0
          RADTEM(I)=(TWALL(I,1)*ASIDE+TWALL(I,3)*AGLASS+TWALL(I,4)*AFLOOR)
          1/(ASIDE+AGLASS+AFLOOR)
400       CONTINUE
C         ****************************************************************
          [illegible](I)=0
          [illegible]=(RC(I,4)-AMC(I,1)*TMEAN(I))*LEN/23.0
          [illegible](I))*LEN/23.0
```

```
      QTOT(I+1)=0
      QTOTAL(I)=QTSTRU(I)+QTRELE(I)
      QTOTAT(I)=0.0
      WATREA(I)=STRIPL*AREA*LEN/23.0
      QTREGL(I)=QTRELE(I)+WREGEA(I)
      QTSTRU(I+1)=QTSTRU(I)
      QTRELE(I+1)=QTRELE(I)
      QTRELE(I+1)=QTRELE(I)
      QTOTAL(I+1)=QTOTAL(I)
C     ************************************************************
  350 CONTINUE
C     ****************************************************************
      ITERA=ITER
      TEXIT=T(24)
      WEXIT=W(24)
      HINL=CPA*TINL+WINL*(2501.4+1.884*TINL)
      HEXIT=CPA*TEXIT+WEXIT*(2501.4+1.884*TEXIT)
      DH=FLOMAS(M)*(HEXIT-HINL)
      QTON=DH/12600.0
      WATADD=FLOMAS(M)*(WINL-WA)
      TON=QTOTAL(24)/12600.0
      LOAD=QTOTAL(24)
      TONSF=TON*1.1
      EVAPWA=FLOMAS(M)*(WEXIT-WINL)
      RISE=TEXIT-TINL
       AVGTEM=(TEXIT+TINL)/2.0
      WRITE(31,*),ITER,FLOMAS(M),TDB,TWB,TDB1,TWB1,TINL,TEXIT,AVGTEM,
     1RISE,TON,TONSF,QTON,U(1,2,1),TSOL(1,2,1),XMEAN(1),TMEAN(1),U(23
     1,2,1),TSOL(23,2,1),XMEAN(23),TMEAN(23)
      PVEXIT=1.0132*WEXIT/(WEXIT+0.622)
      WAV=(WINL+WEXIT)/2.0
      PVTAV=1.0132*WAV/(WAV+0.622)
      PSEXIT=PS(TEXIT)
      RHEXIT=PVEXIT/PSEXIT
      MA(M)=FLOMAS(M)
      IF(ITER .EQ. 1) GO TO 1100
      TDBDIF=ABS(TPR(ITER-1)-TPR(ITER))
      IF(TDBDIF .GT. 0.05) GO TO 1666
      GO TO 215
 1100 TRACK=TDB-TEXIT
      IF(TRACK .GT. 3.0) GO TO 1666
      GO TO 215
 1666 CONTINUE
  215 CONTINUE
      IF((RHINL .GT. 0.90) .OR. (RHEXIT .GT. 0.90)) GO TO 1277
      GO TO 12500
 1277 WRITE(46,8444)
12500 CONTINUE
C     ****************************************************************
C     CALCULATION OF AIR WASHER DIMENSIONS
C     *****************************************************************
      HDAV=5000.0
      VFACE=2.4*3600.0
      SPVOLA=287.2*(TDB1+273.16)/((1.0132-PV(TDB1,TWB1))*1.0E05)
      FLOW(M)=FLOMAS(M)*SPVOLA
      Z=-ALOG(1.0-EFF)
      VOLAW=FLOMAS(M)*Z/HDAV
      AFACE=FLOW(M)/VFACE
      LENAW=VOLAW/AFACE
C     ****************************************************************
C     CALCULATION OF COMFORT VELOCITY BY FANGER'S EQUATION
C     *************************************************************
      IF(CASE .EQ. 2) GO TO 111
      MRT=(RADTEM(1)+RADTEM(23))/2.0
  111 MRT=AVGTEM
      CALL FANGER(METAB,WEFF,MRT,ADU,FCL,ICL,PVTAV,AVGTEM,HC)
      COMFV=(HC/10.4)**2
C     ***********************************************************
C     CALCULATION OF DUCT DIMENSIONS AND BLOWER HP
C     ***********************************************************
      WDMM=300.0
      HDMM=200.0
      WDM=WDMM/1000.0
      HDM=HDMM/1000.0
      PR1=WDM*HDM
      PR2=WDM+HDM
      DIA=1.265*(PR1**3/PR2)**0.2
      ROUGH=1.0/[illegible]
      FACT=1.0/(1.74-2.0*ALOG(2.0*ROUGH/DIA))
      [illegible]=[illegible]/(PR1*[illegible])
```

```
765   FORMAT(1X,80('=')/5X,'NO HTEXCHANGER REQUIRED',5X,'MA(KG/H)=',
     1I5,5X,'PLACE=',I2,'ROUTE=',I2/10X,80('='))
      GO TO 2080
105   WRITE(15,809),IFORAT,MA(M),PLACE,ROUTE
809   FORMAT(1X,80('=')/5X,'REGENERATIVE HTEXCHANGER REQUIRED',2X,'
     1NUMBER OF STATIONS=',I2,2X,'MA(KG/H)=',I5,2X,'PLACE=',I2,2X,
     1'ROUTE=',I2/10X,80('=')///)
2080  WRITE(15,12),PLACE,TDB,TWB,TDB1,TWB1,MA(M),EFF,TING,TEXIT,AVGTEM
     1,RISE,TESTRO(24),STPRDE(24),LOAD,TDS,IOPSF,WATADD,POWER,QTOT,
     1X(3),T(3),X(12),T(12),X(20),T(20)
12    FORMAT(5X,I2,4(1X,F4.1),4X,I5,1X,F4.2,3X,F4.1,2(4X,F4.1),3X,F4.1
     1,2X,I5,1X,I5,1X,I5,1X,F5.2,3X,F4.2,4X,F6.2,2X,F6.1,3X,
     1F4.2,  7X,F5.2,3X,F4.1,5X,F5.2,3X,F4.1,5X,F5.2,3X,F4.1)
8444  FORMAT(5X,20('=')/'REQ.HUMIDITY TOO HIGH(NOT FEASIBLE'/5X,20('='
     1))
      WRITE(16,13),PLACE,TDB,TWB,RHTDB,MA(M),TDB1,TWB1,RHTDB1,EFF,
     1TING,RHING,TEXIT,RHEXIT,WA,WTDB1,WING,WEXIT,WRT,COPEV
13    FORMAT(5X,I2,1X,F4.1,4X,F4.1,1X,F5.2,2X,I5,4X,F4.1,4X,F4.1,2X,
     1F5.2,2X,F4.2,2X,F4.1,3X,F5.2,4X,F4.1,2X,F5.2,3(2X,F6.4),3X,F4.1
     1,3X,F8.2)
      WRITE(17,14),PLACE,TDB,TWB,MA(M),SPVOLA,EFF,IFLOW(M),IVFACE,
     1LENGW,AFACE,VOLAN,WATADD
14    FORMAT(5X,I2,4X,F4.1,4X,F4.1,6X,I5,3X,F4.2,5X,F4.2,4X,I6,9X,I4,
     12X,F5.2,4X,F5.2,2X,F6.2,4X,F6.2)
      WRITE(18,15),PLACE,TDB,TWB,MA(M),VDUCT,IFLOW(M),PDROP,DIA,HOM,
     1ADM,POWER
15    FORMAT(5X,I2,2(4X,F4.1),6X,I5,7X,F6.1,5X,I6,6X,F6.1,3X,F6.2,2X
     1,F4.2,3X,F4.2,3X,F6.1)
C     FORMAT(5X,F4.1,1X,F6.1,4X,I2,4X,F5.2,3(1X,F4.1),4X,F6.2,4X,F5.2
C    1,F7.4,2X,F5.2,3(2X,F6.2))
C     ****************************************************
88    CONTINUE
2000  CONTINUE
1000  CONTINUE
6500  CONTINUE
5500  CONTINUE
412   CONTINUE
      STOP
      END
C     ****************************************************
C     SUBPROGRAM 1 FOR TIME
C           **********************************************
      FUNCTION TIME(LAPPTM,NOON)
      REAL LAPPTM,NOON
      INTEGER TIME
      IF(LAPPTM .LT. NOON) GO TO 1
      CONTINUE
      IF(LAPPTM .GT. NOON) GO TO 2
      CONTINUE
      IF(LAPPTM .EQ. NOON) GO TO 3
1     TIME=1
      RETURN
2     TIME=2
      RETURN
3     TIME=3
      RETURN
      END
C     ****************************************************
C     SUBPROGRAM 2 FOR PV
C     ****************************************************
      FUNCTION PV(TPRDB,TPRWB)
      PV=PS(TPRWB)-(1.0132-PS(TPRWB))*(TPRDB-TPRWB)/(1547.-1.44*TPRWB)
      RETURN
      END
C     ****************************************************
C     SUBPROGRAM 3 FOR PS
C     ****************************************************
      FUNCTION PS(TC)
      TK=TC+273.16
      DK=EXP((7.21379+(1.1520E-05-4.787E-09*TK)*(TK-483.16)**2)*
     1(647.31/TK-1.0))
      PSATA=225.65/DK
      PSBAR=PSATA/1.02
      PS=PSBAR
      RETURN
      END
C     ****************************************************
C     SUBPROGRAM 4 ... FOR TILT ANGLE OF SURFACE
C     ****************************************************
      REAL FUNCTION ...(SJ,SSIDER)
```

```
      RETURN
      END
C     ******************************************************************
C     FUNCTION SUBPROGRAM 5 AG FOR GAMMA ANGLE
C     *****************************************************************
      FUNCTION AG(BSIDER,BIT,BSIGH,BPHI,BLAT,BDEC)
      INTEGER BSIDER,BIT
      DIMENSION BSIGH(2)
      IF(BIT.EQ.3) GO TO 35
      CONTINUE
      IF(BSIDER.EQ.1 .AND. BIT.EQ.1) GO TO 30
      CONTINUE
      IF(BSIDER.EQ.2 .AND. BIT.EQ.1) GO TO 31
      CONTINUE
      IF(BSIDER.EQ.1 .AND. BIT.EQ.2) GO TO 32
      CONTINUE
      IF(BSIDER.EQ.2 .AND. BIT.EQ.2) GO TO 33
30    AG=ABS(BPHI-BSIGH(BSIDER))
      RETURN
31    AG=BPHI+BSIGH(BSIDER)
      RETURN
32    AG=BPHI+BSIGH(SIDER)
      RETURN
33    AG=ABS(BPHI-BSIGH(SIDER))
      RETURN
35    IF(BLAT .GT. BDEC) GO TO 34
      AG=180.0
      RETURN
34    AG=0
      RETURN
      END
C     ****************************************************************
C     FUNCTION SUBPROGRAM 6 FOR  FSS
C     *********************************************************
      FUNCTION FSS(BJR,BSIDER,BRTHET)
      INTEGER BJR,BSIDER
      DIMENSION BRTHET(4,2)
      IF(BJR .EQ. 2) GO TO 91
      COSRTH=COS(BRTHET)
      IF(COSRTH .GT. -0.2) GO TO 92
      FSS=0.45
      RETURN
92    FSS=0.55+0.437*COSRTH+0.313*(COSRTH**2)
      RETURN
91    FSS=1.0
      RETURN
      END
C     ***********************************************************
C     FUNCTION SUBPROGRAM 7 FOR FSG
C     ***************************************************************
      FUNCTION FSG(BJR,BSIDER)
      INTEGER BJR,BSIDER
      IF(BJR .EQ. 2) GO TO 85
      FSG=0.5
      RETURN
85    FSG=0
      RETURN
      END
C     **************************************************************
C     FUNCTION PROGRAM 8 FOR REFL OF GLASS(INTERPOLATED)
C     LAGRANGIAN INTERPOLATION FOR THGLAS > 50.0
C     LINEAR INTERPOLATION FOR THGLAS</= 50.0
C     ***************************************************************
      FUNCTION REFL(GLASST)
      REAL L0,L1,L2,L3,L4
      IF(GLASST .LE. 50.0) GO TO 75
      L0=(GLASST-60.0)*(GLASST-70.0)*(GLASST-80.0)*(GLASST-90.0)
      L1=(GLASST-50.0)*(GLASST-70.0)*(GLASST-80.0)*(GLASST-90.0)
      L2=(GLASST-50.0)*(GLASST-60.0)*(GLASST-80.0)*(GLASST-90.0)
      L3=(GLASST-50.0)*(GLASST-60.0)*(GLASST-70.0)*(GLASST-90.0)
      L4=(GLASST-50.0)*(GLASST-60.0)*(GLASST-70.0)*(GLASST-80.0)
      REFL=0.06*L0/(24.E4)-0.09*L1/(6.E4)+0.165*L2/(4.E4)-0.38*L3/
     1(6.E4)+1.0*L4/(24.E4)
      RETURN
75    REFL=0.02+(8.0E-4)*GLASST
      RETURN
      END
C     **************************************************************
C     SUBROUTINE NEWTON FOR OPEN;NEWTON-RAPHSON METHOD OF ITERATION
C     **************************************************************
```

```
      [illegible],BJR))*(Z1**BY(BJR))-BZSIDE(BIR,BJR,BSIDER)+BT(BIR
     1,BJR)
      FDIF=1.0+BY(BJR)*BROP(BIR,BJR)*(Z1**BEXPON(BJR))
      Z2=Z1-(FUNC/FDIF)
      IF(ABS(Z2-Z1) .LE. 0.01) GO TO 11
      Z1=Z2
44    CONTINUE
11    SDEP(BIR,BJR,BSIDER)=Z2
      RETURN
```

PLE Page Limit Exceeded